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SYSTEMS STUDY OF A MANNED ORBITAL TELESCOPE

MIDTERM REPORT

D2-90747-1

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THE BOEING COMPANY AERO-SPACE DIVISION
SEATTLE, WASH.

MANNED ORBITAL TELESCOPE SYSTEMS STUDY
MIDTERM REPORT

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Contract No. NAS1-3968

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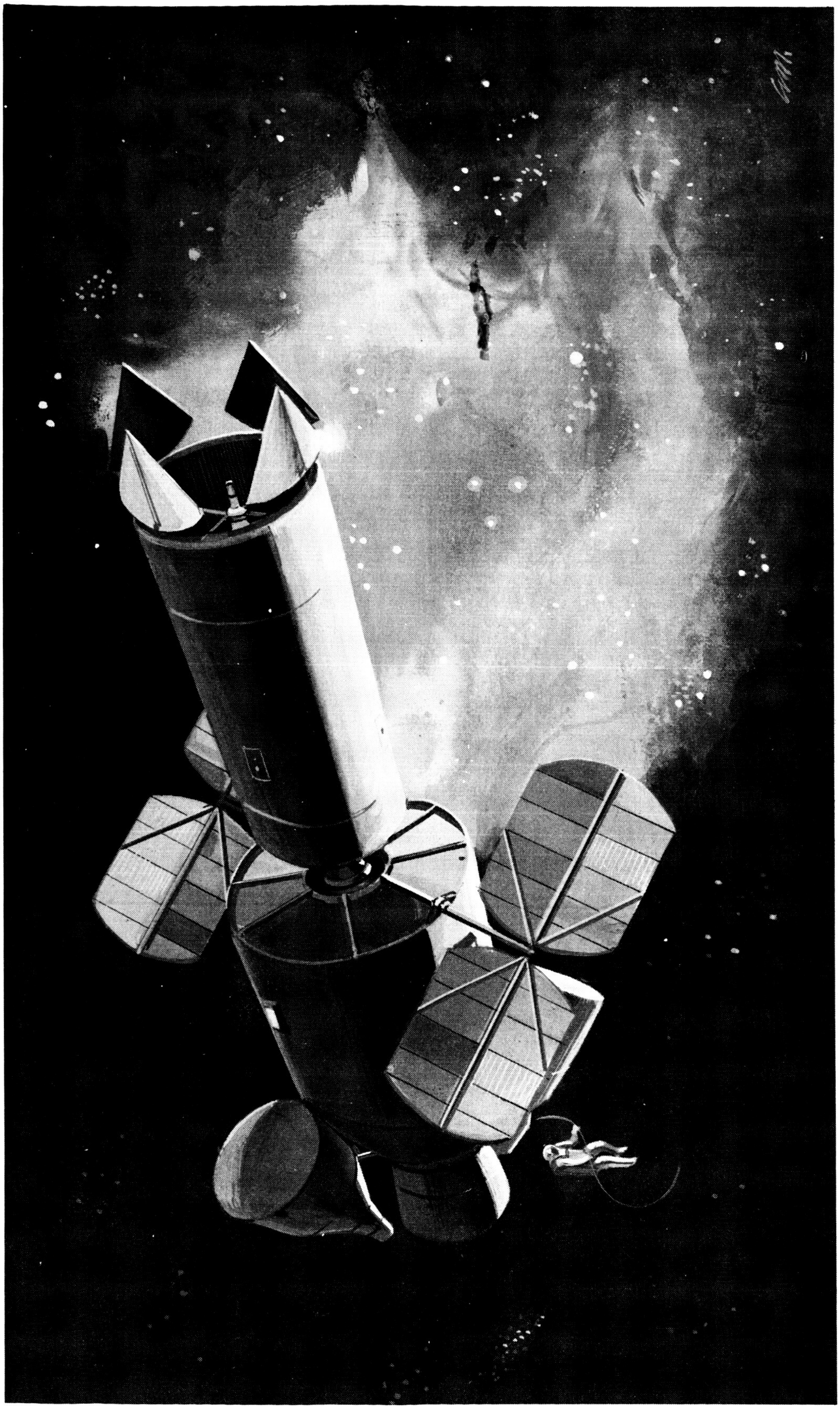
Aero-Space Division
THE BOEING COMPANY
Seattle, Washington



CONTENTS

SYSTEMS STUDY OF A MANNED ORBITAL TELESCOPE

MID-TERM REPORT

STUDY OBJECTIVES

The prime objective is to determine the feasibility of designing, fabricating, launching, and operating a manned 120-inch orbiting telescope. To accomplish this, it is necessary to investigate possible modes with special emphasis on man's role and to indicate areas where state-of-the-art advances are necessary. It should be emphasized that this is not primarily a design study and that only sufficient engineering design will be accomplished to select the best operational mode and to define technology areas where state-of-the-art advances are necessary.

STUDY OBJECTIVES

- DETERMINE FEASIBILITY OF:
  - DESIGN
  - FABRICATION
  - LAUNCH
  - OPERATION
- INVESTIGATE POSSIBLE OPERATIONAL MODES WITH SPECIAL EMPHASIS ON MAN'S ROLE
- ACCOMPLISH NECESSARY ENGINEERING STUDIES, ANALYSIS, DESIGN AND PLANNING REQUIRED TO SELECT BEST OPERATIONAL MODE AND OBSERVATORY DESIGN
- INDICATE AREAS OF TECHNOLOGY WHERE STATE-OF-THE-ART ADVANCES ARE NECESSARY

SCIENTIFIC CAPABILITY COMPARISON

This is a comparison of the capability of the MOT with ground-based telescope for various types of observation and the relative importance of these observation types to the MOT. The relative importance assigned is fairly arbitrary and there is undoubtedly a great divergence of opinion of this relative importance among astronomers.

The main limitation on ground-based telescopes for spectrographic, photoelectric, and thermoelectric work is the presence of the atmosphere which acts as a filter for all but some very narrow bands (in the visible and the IR) in the electromagnetic frequency spectrum to be covered by the MOT. This range at present is assumed to be from the Lyman limit (930Å) to approximately one millimeter. Astrometric work and planetary photographs in ground-based telescopes are restricted by the phenomena of atmospheric "seeing" which limits the resolution on the average to 1 second of arc or slightly better whereas in the case of the MOT there is no basic reason why the full diffraction limit of 0.05 second of arc could not be achieved.

In the case of the Orbiting Astronomical Observatory (OAO), limited capability exists in the first four categories with no capability in the latter three categories.

SCIENTIFIC CAPABILITY COMPARISON

COMPARISON / OBSERVATION	GROUND BASED TELESCOPES	MOT	% OF MOT OBSERVATION TIME
HIGH DISPERSION SPECTRA VISIBLE & UV	VISIBLE SPECTRUM RANGE	LIMITED BY CUMULATIVE EXPOSURE TIME	30
LOW DISPERSION SPECTRA	VISIBLE SPECTRUM RANGE	LIMITED BY CUMULATIVE EXPOSURE TIME	20
PHOTOELECTRIC PHOTOMETRY	VISIBLE SPECTRUM RANGE	• GREATER RESOLUTION • FAINTER SOURCES	5
PHOTOGRAPHIC ASTROMETRIC & ASTROPHYSICAL	LIMITED BY SEEING CONDITIONS (1 ARC SEC) AND ABSORPTION OF IR & UV	• ASTROMETRIC - 0.05 ARC SEC RESOLUTION • COMPLETE SPECTRUM	30
HIGH DISPERSION IR SPECTRA	ONLY THROUGH NARROW WINDOWS (8 - 13 μ)	LIMITED ONLY BY EXPOSURE TIME	5
THERMOELECTRIC MEASUREMENTS	ONLY THROUGH NARROW WINDOWS (8 - 13 μ)	LIMITED ONLY BY SOURCE INTENSITY	5
PHOTOGRAPHIC (PLANETARY)	LIMITED BY SEEING CONDITIONS (1 ARC SEC OR SLIGHTLY BETTER)	0.05 ARC SEC RESOLUTION	5

MOT — MODES OF OPERATION

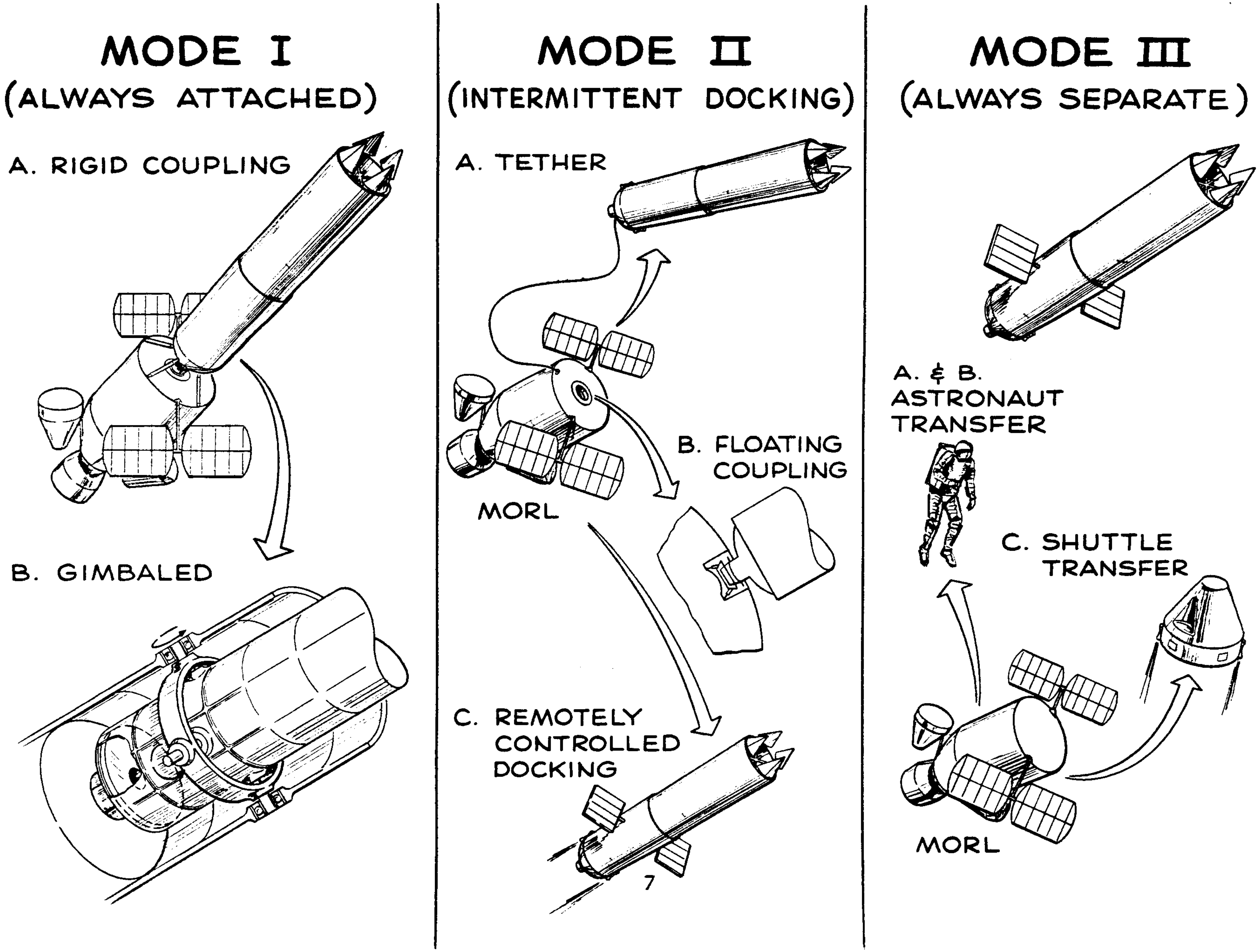
The three basic modes of operation for the telescope illustrated here are:

Mode I — The telescope is docked and then permanently attached to the laboratory for all subsequent operations. There are two alternates under this mode: (A) Rigid Coupling, and (B) Gimbaled Coupling.

Mode II — The telescope module is docked and rigidly attached to the laboratory for experiment setup and maintenance. The telescope module is uncoupled from the laboratory for the astronomical observation functions and then reattached. Mode II alternate system designs are: (A) Tether System, (B) Floating Socket within a limited space and having a mechanical system for acquiring and reattaching the telescope, and (C) Intermittent remote-control docking, but with no physical attachment or floating constraint.

Mode III — The telescope is placed in orbit near the laboratory and is operated in this separated position at all times. Mode III alternate system designs are: (A) Man traveling to the telescope and performing all functions in a space suit, (b) Man traveling to the telescope in a space suit but with a pressurized cabin provided for him to work in, and (C) A shuttle vehicle for transporting man to the telescope then attached to provide a "shirtsleeve" environment.

MODES OF OPERATION



STUDY PROGRAM TO MIDTERM

Mode Insensitive Items

There has been activity in five different categories. For the sake of clarity and convenience these have been separated into items which are not mode sensitive (which appear here) and mode sensitive items which appear next. Note, however, that the work indicated on both charts is parallel.

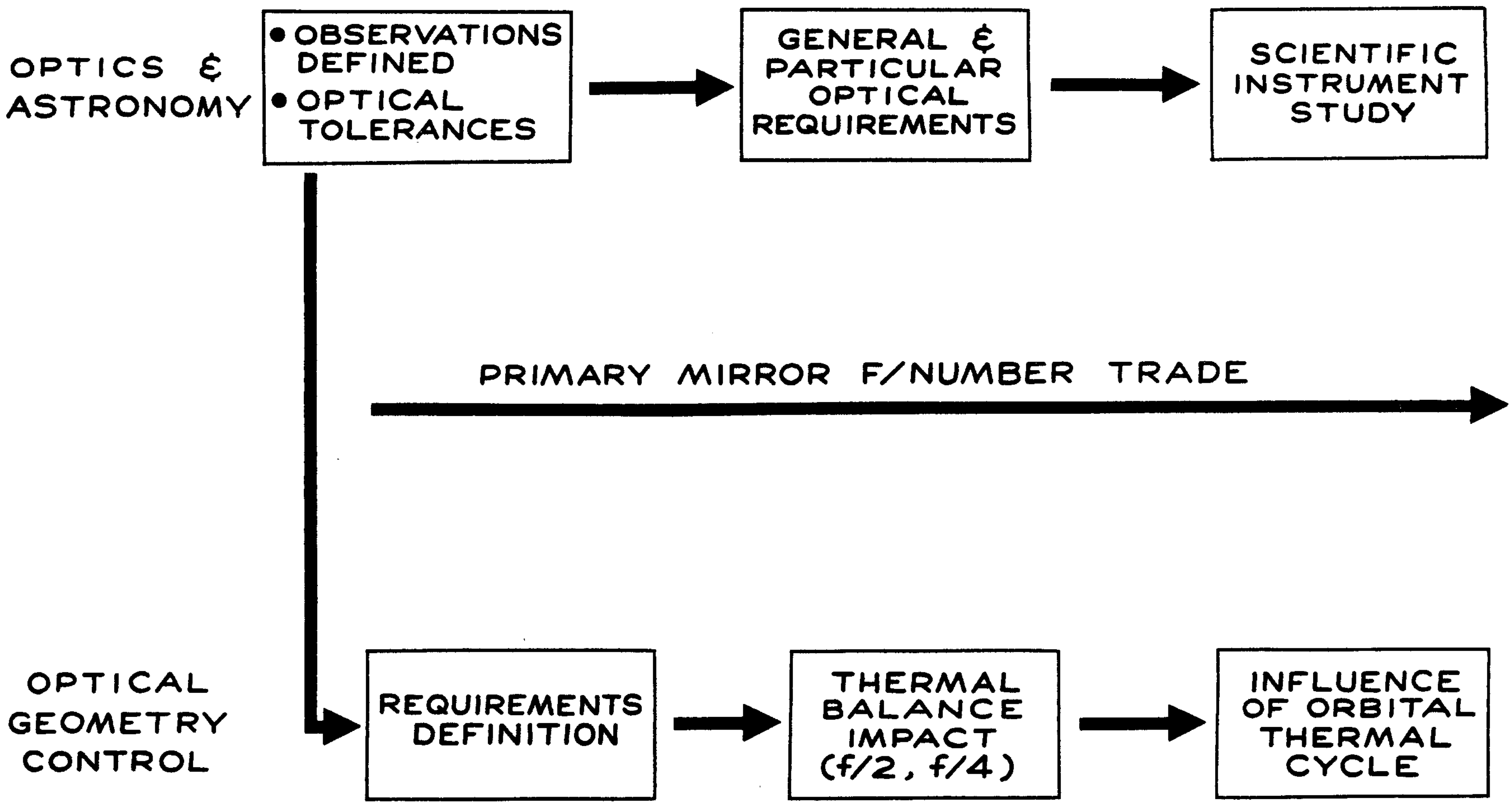
The observations which were mentioned previously led to the general and particular optical requirements and thence to the definition of the scientific insturments. The definition of the scientific instruments was carried to the point where size, weight, and power requirements could be determined and a reasonable cabin arrangement could be postulated.

Fairly early in the program it became apparent that a trade study was necessary to determine whether a primary mirror focal ratio of about two, as was originally proposed, or a more conventional ratio of four should be adopted. The main factors in this trade are the positioning tolerances of the secondary mirrors with respect to the primary and the difficulties of manufacture of a diffraction-limited primary mirror.

The optical tolerances define the requirements for the control of the optical geometry. These were examined in the light of a preliminary thermal balance analysis for an f/2 and an f/4 configuration. The examination of this together with several other factors led to the selection of an f/4 system. Finally, the results of a more detailed orbital thermal balance led to a concept of control of the optical geometry and the identification of the distortion of the primary mirror as a potentially serious problem.

STUDY PROGRAM TO MIDTERM

MODE-INSENSITIVE ITEMS



STUDY PROGRAM TO MIDTERM

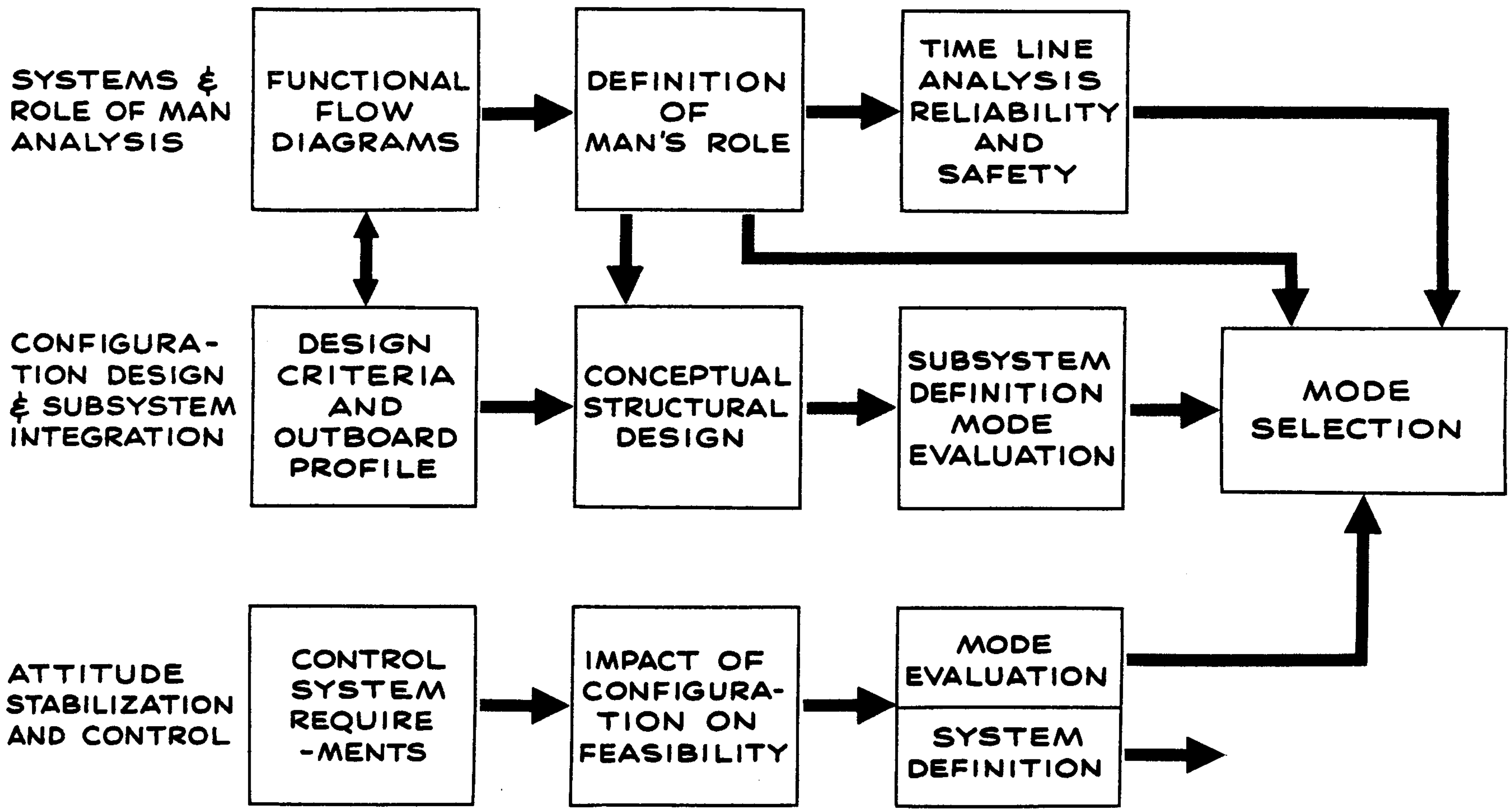
Mode Sensitive Items

This portion of the program was primarily concerned with generating sufficient data for the comparative evaluation of the eight modes of operation and the selection of two of these modes for continued study during the remainder of the program. Some items, such as the role of man analysis and the conceptual design, generated information which was general and mode insensitive.

Functional flow diagrams and outboard profiles generated sufficient data for a definition of man's role, a timeline analysis, and a preliminary assessment of reliability and safety. The work in the areas of conceptual design and subsystems with an assessment of the control problems in the various modes led to a definition of the technical risk involved in each mode and the constraints placed on the MORL by the presence of the MOT. For the evaluation which led to the final mode selection, this information was grouped into three general categories: technical risk; operational capability; and constriants on the MORL and the ratings assigned to each mode. In some areas, particularly under operational capability, it was possible to generate numbers which supported the particular ratings; in other areas a judgment estimate was made based on an assessment of the relative difficulty of the problems involved in each case.

STUDY PROGRAM TO MIDTERM

MODE-SENSITIVE ITEMS



OPTICS AND ASTRONOMY

- OBSERVATIONS
- TYPICAL OBSERVATION PARAMETERS
- SCHEMATIC
- f/2 VS f/4 TRADE

ASTRONOMICAL OBSERVATIONS

In this section we will discuss the types of astronomical observations, the requirements these observations impose on the telescope, and the requirements of the instrumentation to record the data. The types of observations have been divided into two categories — stellar observations and planetary observations. Stellar observations concern observations of stars, star clusters, galaxies, interstellar matter, etc. The planetary observations pertain to observing the planets in the solar system. The stellar observations have been divided into: 1) high-dispersion spectra (in the ultraviolet and visual region); 2) low-dispersion spectrum studies and wide-field photography; 3) narrow-field photography; and, 4) photoelectric photometer. For planetary observations we will discuss: 1) high-dispersion infrared spectra; 2) thermoelectric measurements; and, 3) photography.

The astrophysical photography will be performed at equivalent f/8 focal ratio to photographically record very faint stars, nebulae, or galaxies; perhaps as faint as 18th or 20th magnitudes.

Both photoelectric photometry and astrometric photography are planned at f/15. Photoelectric photometry is performed at f/15 for convenience of instrumentation design. The astrometric photography requires high resolution (about 0.07 arc second) for stars as faint as 23rd magnitude (the approximate limit). This exposure must be made in a half-orbit period.

The instrumentation located at the f/30 focal plane requires maximum resolution obtainable within the constraints imposed by the cabin size.

ASTRONOMICAL OBSERVATIONS

	EFFECTIVE FOCAL RATIO
STELLAR OBSERVATIONS	
• HIGH-DISPERSION SPECTRA	f/30
• LOW-DISPERSION SPECTRA	f/8
• PHOTOELECTRIC PHOTOMETRY	f/15
• PHOTOGRAPHIC	f/8, f/15
PLANETARY OBSERVATIONS	
• HIGH-DISPERSION IR SPECTRA	f/30
• THERMOELECTRIC MEASUREMENTS	f/30
• PHOTOGRAPHIC	f/30
• SPECIALIZED TYPE	f/30

HIGH-DISPERSION SPECTRA

Presented here are the basic guidelines for the high-dispersion spectra instrumentation. The instrumentation feasibility model is determined from these guidelines. It is assumed that almost 1/3 of the observation time will be devoted to high-dispersion spectra studies.

The type of target in such studies is a point source of light. This point source will be imaged by the telescope as a spot of light 6 to 60 microns in diameter, depending on whether the wavelength being observed is in the UV or near IR. The stars used for high-dispersion studies will be 10th magnitude or brighter.

The instrument used will depend on the wavelength region being studied. For the UV region (1200 to 4000 Å), an unsymmetrical Czerny-Turner spectrometer is recommended. This type uses off-axis parabolic mirrors with a plane reflection grating in the collimated beam. Two gratings blazed for 2000 and 3000 Å would be required to cover this UV region. For the 4000- to 8900-Å visual region, a spectrograph using a Cassegrainian collimator and a Cassegrainian-Schmidt spectral camera is recommended. In this case, four plane-reflection/diffraction gratings are required to observe the second order spectrum over the 4000- to 8900-Å spectral range.

The data from the UV spectrometer would be taped as electrical signals, whereas the data from the visual spectrograph would be on photographic film. The guidance requirement for the most stringent case would be ± 0.01 arc second. This depends on the resolution requirements.

Exposure time will average 5 orbits depending on the stellar magnitude and guidance stability.

HIGH-DISPERSION SPECTRA

• TELESCOPE USAGE	30%
• TYPE OF TARGET	POINT OF LIGHT
• BRIGHTNESS	> 10TH MAGNITUDE
• SCIENTIFIC INSTRUMENT	GRATING SPECTROGRAPH OR SPECTROMETER
• TYPE OF DATA	FILM OR TAPE
• GUIDANCE EQUIPMENT	± 0.01 ARC SECOND
• EXPOSURE TIME	AVERAGE 5 ORBITS
• EQUIPMENT FOCAL RATIO	ef/30

HIGH-DISPERSION VISUAL SPECTROGRAPH

4000-8900 Å

The dimensions for the high-dispersion spectrograph were determined for an instrument to resolve 0.1 Å using first and second order spectra. With the present cabin configuration there was not adequate room to fit the first order spectrograph into the cabin. Therefore the second order model was used as a feasibility model. This is a compromise as the first order model has the growth potential of modifying for second order spectra to resolve 0.05 Å. The optical schematics were the same in both cases — merely scaled down.

The collimator is a Cassegrainian optical system using an f/4 primary with a secondary to give an equivalent focal ratio of f/30. The aperture used is four inches.

Four gratings blazed at 4000, 5000, 6000, and 7500 Å are required. The gratings have 15,000 grooves per inch and are mounted on an indexed turret.

The spectral camera is a Cassegrainian-Schmidt system corrected for a 15-degree field. The system has an equivalent focal ratio of f/10 and with the chosen gratings produces a linear dispersion of 8.85 Å/mm.

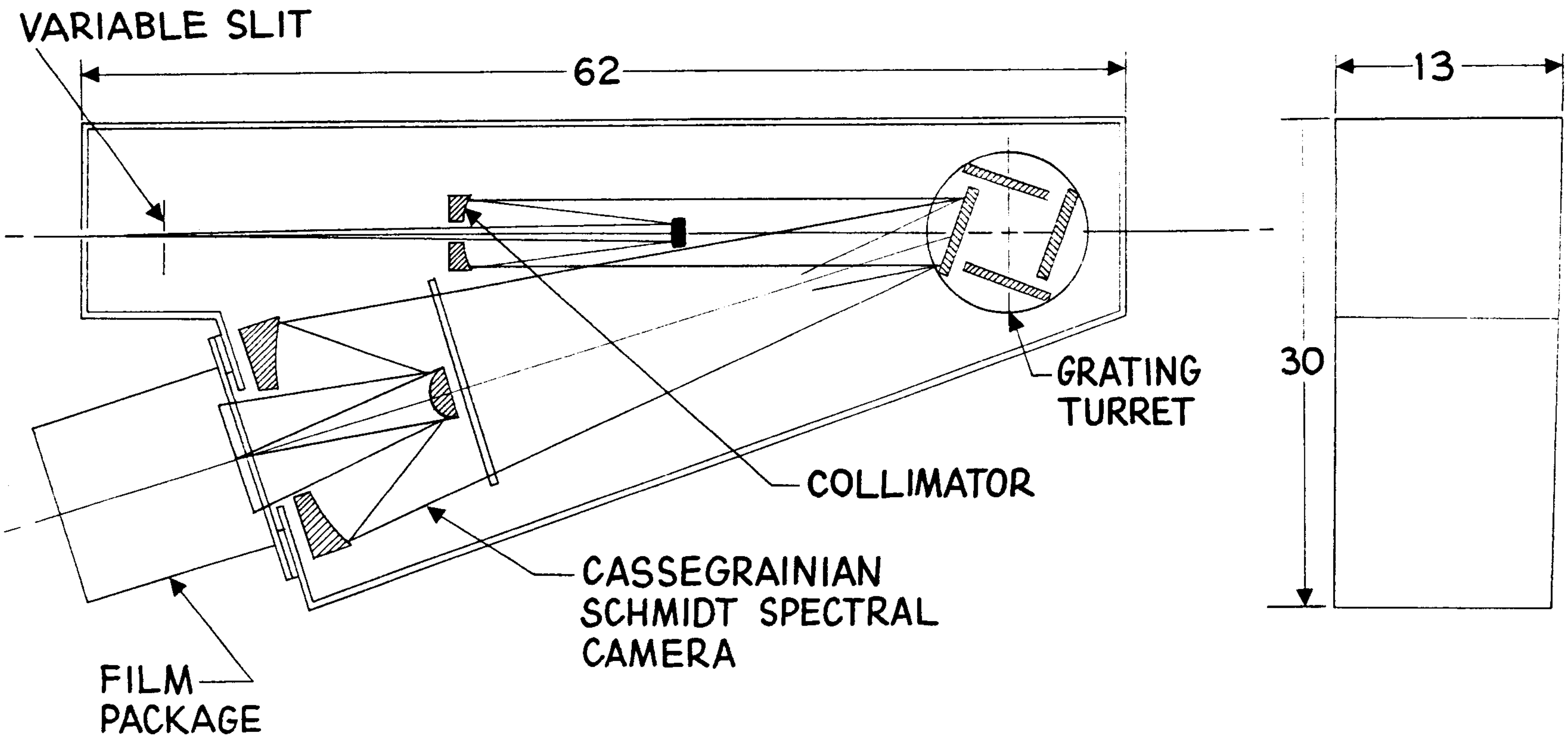
The film required with this spectrograph is E.K. Spectroscopic Film Type IV with a resolution of 136-225 ℓ/mm. The spectral sensitivity of the film required is O, F, and N.

To obtain 0.1 Å resolution at a linear dispersion of 8.85 Å/mm requires a modulation transfer factor of no less than 0.80 at 89 ℓ/mm for the collimator and the spectral camera.

HIGH-DISPERSION VISUAL SPECTROGRAPH

2ND ORDER

f/30



UNSYMMETRICAL CZERNY-TURNER SPECTROMETER

1200-4000 Å

The spectrometer as shown consists principally of: (1) off-axis collimator mirror M_1; (2) plane-reflecting diffraction grating G; (3) off-axis collecting mirror M_2; and (4) a detector arrangement collecting energy through the typical slit S_2.

Since the longest wavelength will be degraded most by the modulation transfer factors of the collimator, grating, and collector, the system is matched for λ = 4000 Å and $\Delta\lambda$ = 0.1 Å. Using a 48-inch focal length collimator and a 30,000 groove per inch grating, the linear dispersion of the collimator is K_c = 0.835 Å/mm, 1.67 Å/mm, and 3.34 Å/mm for λ = 1000, 2000, and 4000 Å, respectively.

In order for the modulation transfer factor of the collimator to be greater than 0.80 at λ = 4000, it is necessary to make the aperture 4 inches. The grating and collector mirror apertures will match the collimator.

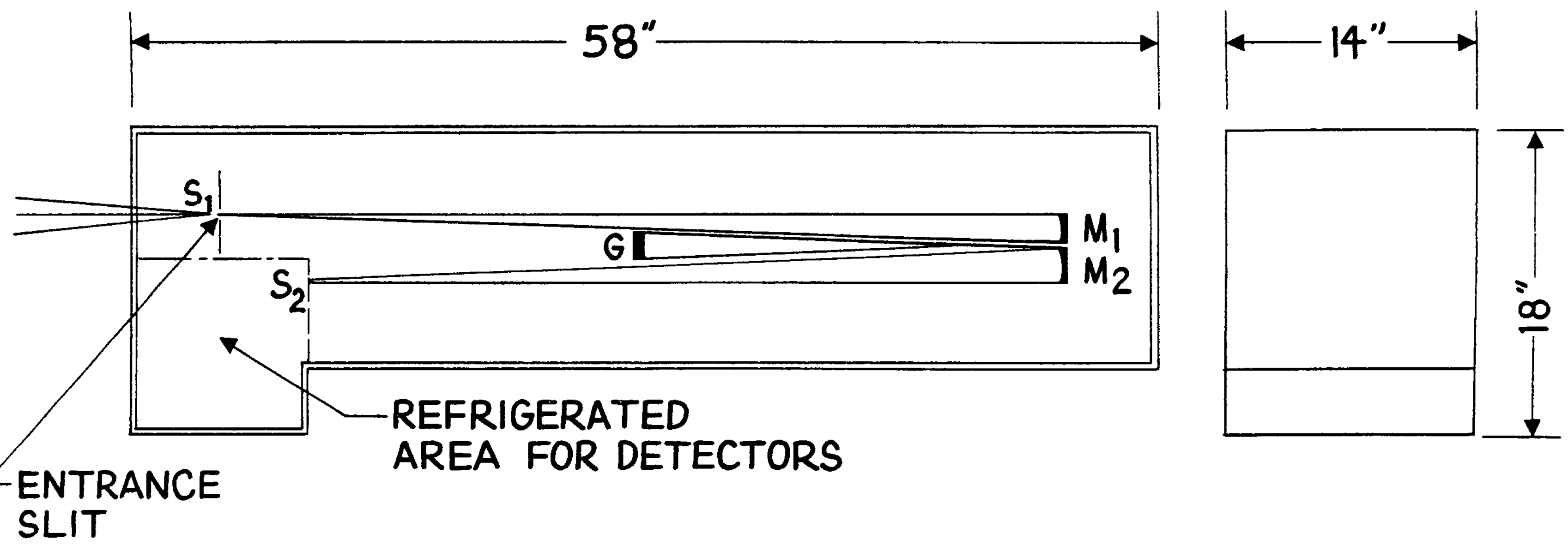
Using two gratings blazed for 2000 and 3000 Å, the limiting factor in this case would be the slit width at S_1 and S_2. For work at λ = 1000 Å, the Airy disc diameter would be ~7 µ. If S_1 and S_2 were matched optically to this, the resolution would be 0.016 Å.

The detector arrangement would probably consist of two photomultipliers with different spectral sensitivity monitoring the spectrum as the grating is rotated. It would also be necessary for similar monitoring of a reference source.

UNSYMMETRICAL CZERNY-TURNER SPECTROMETER

USE 1200 – 4000 Å

f/30 SYSTEM



LOW-DISPERSION SPECTRA

Low-dispersion spectrum studies are similar to the high-dispersion except that they primarily concern faint stars. The planned telescope usage for low-dispersion spectrum studies is 20 percent.

The type of source is a star image (only a point source).

The brightness of the stars in these studies is considerably less than those in the high-dispersion spectra. For low-dispersion spectrum study, stars may be as faint as 20th magnitude. Therefore, study of these stars requires spectral resolution to be compromised for speed in the spectrographic instrument. The resolution of the low-dispersion studies is on the order of 1000 Å at 5000 Å compared to 0.1 Å at 5000 Å for the high dispersion.

The scientific instrumentation would be a grating spectrograph and spectrometer scaled down from the high-dispersion model. The instrument would mount interchangeably with the f/8 wide-field camera.

The data would be in the form of film and tape or chart recordings.

The guidance requirement would be ± 1.0 arc second. This is less stringent because of the wider slit.

The exposure time would average 5 orbits as in high-dispersion studies.

LOW-DISPERSION SPECTRA

- TELESCOPE USAGE 20%
- TYPE OF TARGET .... POINT OF LIGHT
- BRIGHTNESS .... > 20TH MAGNITUDE
- SCIENTIFIC INSTRUMENT .... GRATING SPECTROGRAPH OR SPECTROMETER
- TYPE OF DATA .... FILM OR TAPE
- GUIDANCE REQUIREMENT .... ± 1 ARC SECOND
- EXPOSURE TIME .... AVERAGE 5 ORBITS
- EQUIVALENT FOCAL RATIO ef/8

PHOTOELECTRIC PHOTOMETRY

Photoelectric photometry would be performed in the ultraviolet and visual regions of the spectrum. About 5 percent of the observation time would be devoted to this type.

The source would be the image of a star (essentially a point source).

The brightness of the stars studied would be 20th magnitude or brighter.

The scientific instrument used as a feasibility model is shown in the following figure.

The data would be in either tape or chart record form.

The guidance would be about ± 1 arc second. This requirement would depend on the field stop selected. It is only necessary to guide the telescope so that the image falls within the field stop.

Total observation time would be up to 10 orbits depending on the brightness of the star.

The instrument would be located at the f/15 focal plane.

PHOTOELECTRIC PHOTOMETRY

- TELESCOPE USAGE .... 5 %
- TYPE OF TARGET .... POINT OF LIGHT
- BRIGHTNESS .... > 20TH MAGNITUDE
- SCIENTIFIC INSTRUMENT .... PHOTOMETER PLUS POLARIMETRY ATTACHMENT
- TYPE OF DATA .... TAPE OR CHART RECORDER
- GUIDANCE REQUIREMENT .... ± 1 ARC SECOND
- EXPOSURE TIME .... 10 ORBITS
- EQUIVALENT FOCAL RATIO ef/15

PHOTOELECTRIC PHOTOMETER

Double Channel

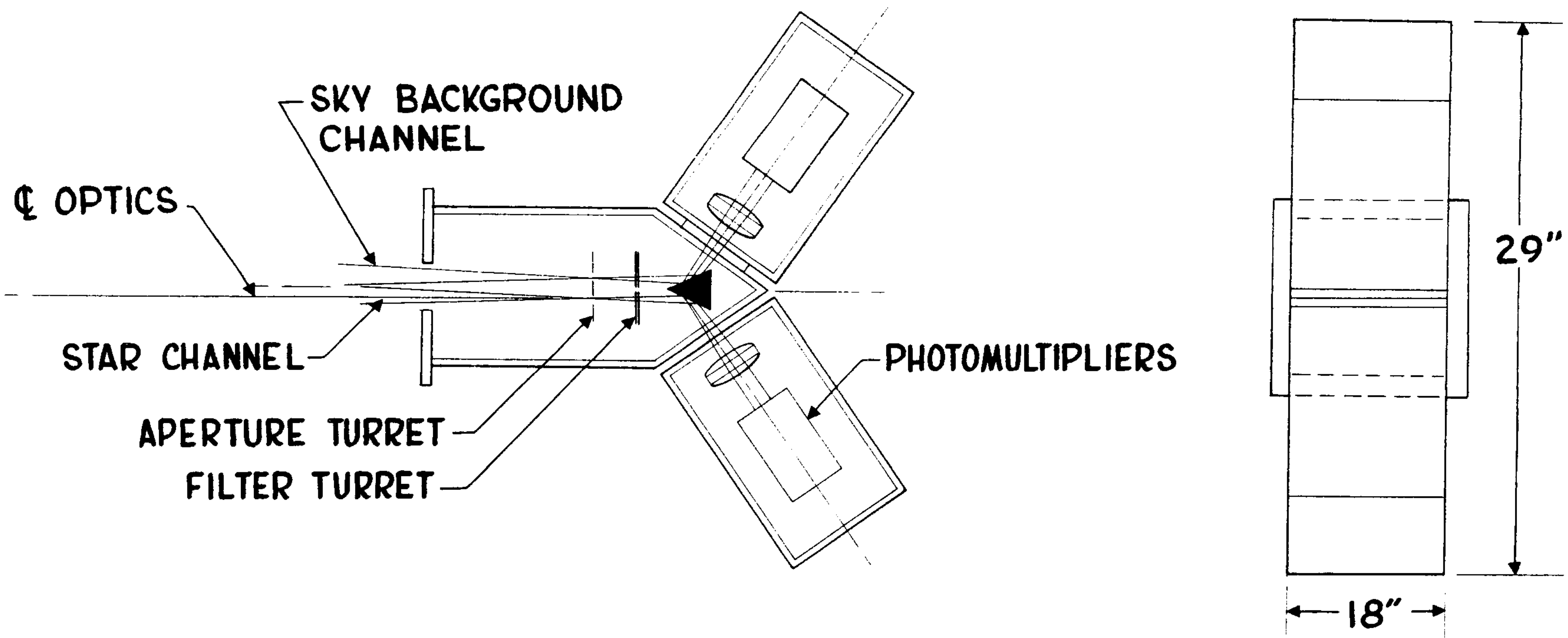
The photometer would be a two-channel device. One channel would measure the brightness of the star and another channel the sky background adjacent to the star. It would be possible to balance these channels with a common source injected periodically ahead of the apertures. Automatically-indexed turrets of apertures and filter would permit remote flexibility in the experiments.

The photometer would be mounted interchangeably with the astrometric camera and would use the same offset guidance.

PHOTOELECTRIC PHOTOMETER

DOUBLE CHANNEL

f/15



PHOTOGRAPHIC

Stellar

Two types of stellar photography are included in the observational program; wide field and narrow field. Their combined observation time would be 25 percent.

The type of target would be extended in the sense that the film format will include more than one star. Each star, however, would still be imaged as a point source.

The field of view would be 0.5 degree for astrophysical studies and 1 minute for astrometric studies.

The astrophysical camera would be a film camera of about 9-inch format. The astrometrical camera would use glass plates of 1 to 3 inches.

The guidance requirement would be ± 0.01 arc second with the exposure time having a maximum of 0.5 orbit. To carry the exposure over into successive orbits would require an unrealistic absolute fine pointing accuracy.

The astrophysical camera would be located at f/8, whereas the astrometric camera would be at f/15. Both cameras would require a field corrector lens.

PHOTOGRAPHIC

STELLAR

- TELESCOPE USAGE .... 25 %
- TYPE OF TARGET .... EXTENDED
- FIELD OF VIEW .... ASTROPHYSICAL 1/2°
ASTROMETRIC 1 MIN
- SCIENTIFIC INSTRUMENT .... CAMERA + FILTERS
- TYPE OF DATA .... FILM
- GUIDANCE REQUIREMENT .... ±0.01 ARC SECOND
- EXPOSURE TIME .... 0.5-ORBIT MAXIMUM
- EQUIVALENT FOCAL RATIO ASTROPHYSICAL-ef/8
ASTROMETRIC-ef/15

HIGH-DISPERSION INFRARED SPECTRA

The purpose of this study would be to measure the emission and reflection spectra of the planets over as broad a wavelength interval as possible (1 to 50 microns). Approximately 5 percent of the observation time would be used for this purpose.

The type of target would be the major planets — possibly Venus. Therefore, the target subtends less than 1 minute of arc. The field of view of the spectrometer slit would be less than 1 minute of arc and as small as 1 arc second. The field of view in many cases would be much smaller than the angle subtended by the planet. The brightness of the planet may be as faint as 6th magnitude (Uranus) and as bright as -4 (Venus).

The scientific instrument recommended as a feasibility model would be a Czerny-Turner spectrometer using a mosaic of four gratings to cover the 0.79 to 13 micron region. It would be possible to replace the grating mosaic with ones blazed for other wavelength regions.

The guidance requirement is extremely difficult due to the relative motion of the Earth and the other planets. A pointing stability as high as 0.01 arc second will be required.

The exposure time is listed as 1/2 to 5 orbits.

The instrumentation would be located at the f/30 focal plane to permit adequate field of view in regard to the telescope. The planetary image will, in many cases, be larger than the slit. Data would be recorded on tape.

HIGH-DISPERSION IR SPECTRA

- TELESCOPE USAGE 5%
- TYPE OF TARGET .... <1 MINUTE
- FIELD OF VIEW .... 1 ARC SECOND
- BRIGHTNESS .... 15TH MAGNITUDE OR BRIGHTER
- SCIENTIFIC INSTRUMENT .... GRATING SPECTROMETER
- TYPE OF DATA .... TAPE OR CHART RECORDER
- GUIDANCE REQUIREMENT .... ±0.1 ARC SECONDS
- EXPOSURE TIME .... 0.5 TO 5 ORBITS
- EQUIVALENT FOCAL RATIO ef/30

CZERNY-TURNER INFRARED SPECTROMETER

0.79-13 Microns

The spectrometer feasibility model for the infrared region of 0.79 to 13 microns consists of: (1) a f/30 Cassegrainian collimator with an effective focal length of 168 inches; (2) a mosaic of four echelette gratings or a 10-inch echelette grating; (3) an f/6 off-axis paraboloidal collector mirror; and (4) exit slits followed by the infrared detectors.

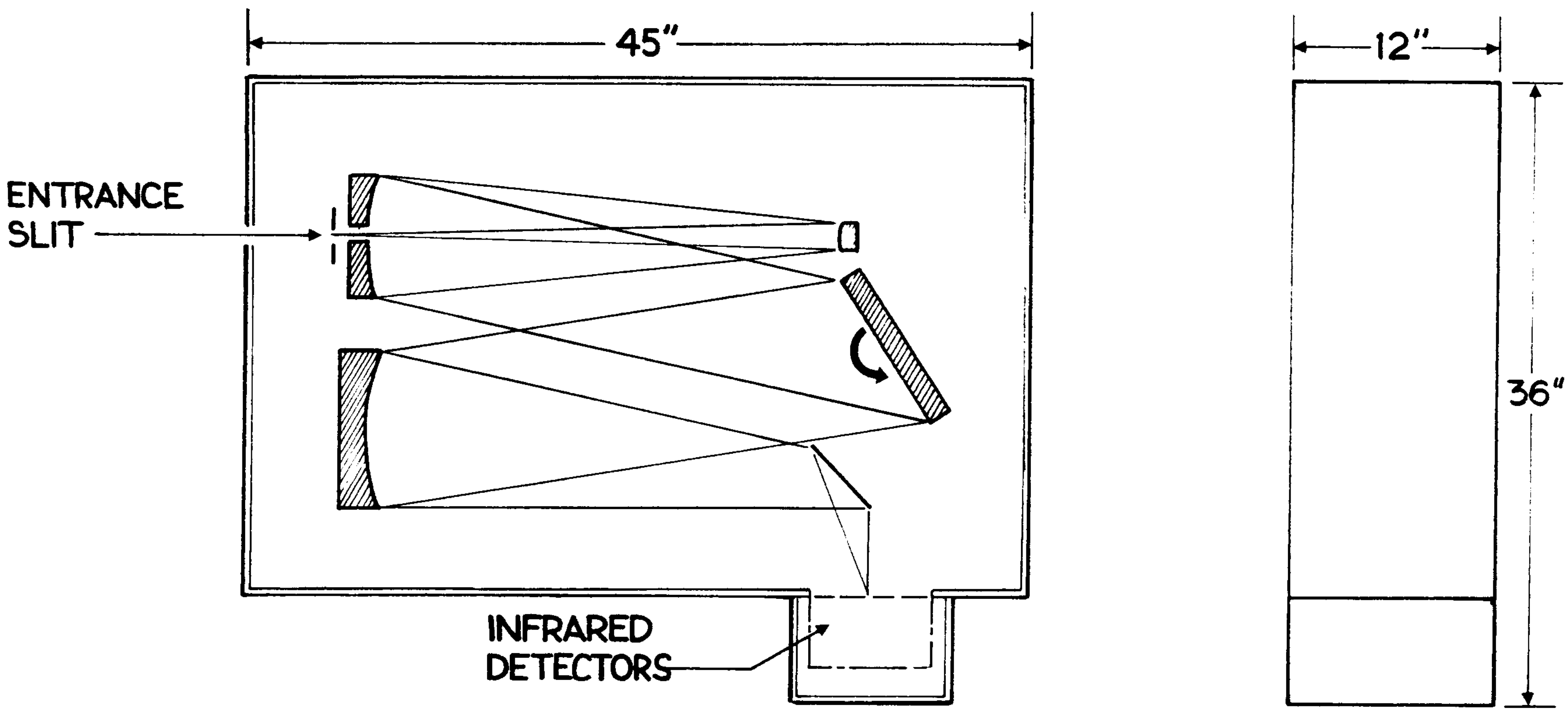
The grating would be rotated precisely to produce a spectral scan by the exit slits. The grating would consist of a mosaic of four echelette gratings or could be a single 10-inch grating. If the mosaic was used, the four component gratings would be blazed for 0.85, 1.7, 4.5, and 10 microns with two having 600 ℓ/mm, and one each 250 ℓ/mm and 100 ℓ/mm, respectively. If the single 10-inch echelette grating was used to observe the 2.5- to 15-micron region, the grating would be 94 ℓ/mm and blazed at 10 microns in the first order. The spectral region and the order observed would be: 2.5-3 μ (fourth order); 3-4 μ (third order); 4-7 μ (second order); and 7-15 μ (first order). This would produce better resolution than is obtainable with prisms.

The collecting mirror would be an f/6 off-axis paraboloidal mirror with several slits in the focal plane. These slits would be followed by the appropriate infrared detector. This would provide simultaneous scan of several portions of the spectrum and a scan by multiple detectors. The resolution expected would be one to two waves per centimeter.

UNSYMMETRICAL CZERNY-TURNER SPECTROMETER

INFRARED REGION 0.79 - 13 MICRONS

f/30 SYSTEM



THERMOELECTRIC MEASUREMENTS

Thermoelectric measurements will consist essentially of scanning the target (planet) with an infrared detector. About 5 percent of the observation time is allotted to this type of observation.

The type of target may be considered extended but will subtend less than 1 minute of arc.

The field of view as determined by the instrumentation might be from 0.2 arc second up to 1 minute of arc.

The brightness of the target may be as faint as 15th magnitude.

The scientific instrument would be an infrared radiometer employing any one of many different detectors — depending on the experimental requirements.

The data would be tape or chart recorded with synchronizing pulses relating to the scan frame.

The guidance requirement would be approximately 0.1 arc second.

Exposure time may be up to 10 orbits to perform a scan of the planet surface.

The instrument would be located at the f/30 focal plane. It is even conceivable that a common reference mounting surface could be located at each focal plane of the several focal ratios.

THERMOELECTRIC MEASUREMENTS

- TELESCOPE USAGE .... 5 %
- TYPE OF TARGET .... < 1 MINUTE
- FIELD OF VIEW .... 0.2 ARC SECOND TO 1 MINUTE
- BRIGHTNESS .... 15TH MAGNITUDE OR BRIGHTER
- SCIENTIFIC INSTRUMENT .... RADIOMETER
- TYPE OF DATA .... TAPE OR CHART RECORDER
- GUIDANCE REQUIREMENT .... ~ 0.1 ARC SECOND
- EXPOSURE TIME .... UP TO 10 ORBITS
- EQUIVALENT FOCAL RATIO ef/30

PHOTOGRAPHIC

Planetary

The objectives of planetary photography will be to obtain the highest photographic resolution possible and to accurately observe surface detail and movement of planetary cloud cover. To obtain maximum resolution the focal length of the telescope must be long enough so that the grain of the photographic film will not limit the resolution.

Also, for such high performance photography, the optical alignment, focus, and guidance stability should be at peak adjustment.

Budgeting 5 percent of the observation time for this type of observation does not mean downgrading in high-performance photography in priority — it simply means that it can be done quickly.

The field of view is less than 1 arc minute and the brightness may be as faint as 15th magnitude or as bright as -4th magnitude.

The photographic instrument would be a cine camera (probably 70 mm) with ultraviolet, red, and blue filters.

The data would be recorded on film in casettes that are pressurized with an optical window.

Guidance stability would be about 0.01 arc seconds with absolute pointing in the order of 10 percent of the field of view.

The exposure time would be 1/10 of a second or longer depending on the brightness of the planet and the film/filter combination.

The camera will be located at the f/30 focal plane to attain maximum photographic resolution.

PHOTOGRAPHIC

(PLANETARY)

• TELESCOPE USAGE	5 %
• TYPE OF TARGET	< 1 MINUTE
• FIELD OF VIEW	< 1 MINUTE
• BRIGHTNESS	15TH MAGNITUDE OR BRIGHTER
• SCIENTIFIC INSTRUMENT	CAMERA + FILTERS
• TYPE OF DATA	FILM OR PLATE
• GUIDANCE REQUIREMENT	~ 0.01 ARC SECOND
• EXPOSURE TIME	~ 0.1 SEC. TO 45 MIN.
• EQUIVALENT FOCAL RATIO	ef /30

OPTICAL SCHEMATIC

This optical schematic represents the current centerline concept. The optical elements and the light paths are shown in relation to the overall telescope configuration which is shown in phantom. An f/4 primary mirror is used and three secondary mirrors are oriented to provide system equivalent focal ratios of f/8, f/15, and f/30 at the three focal planes as indicated.

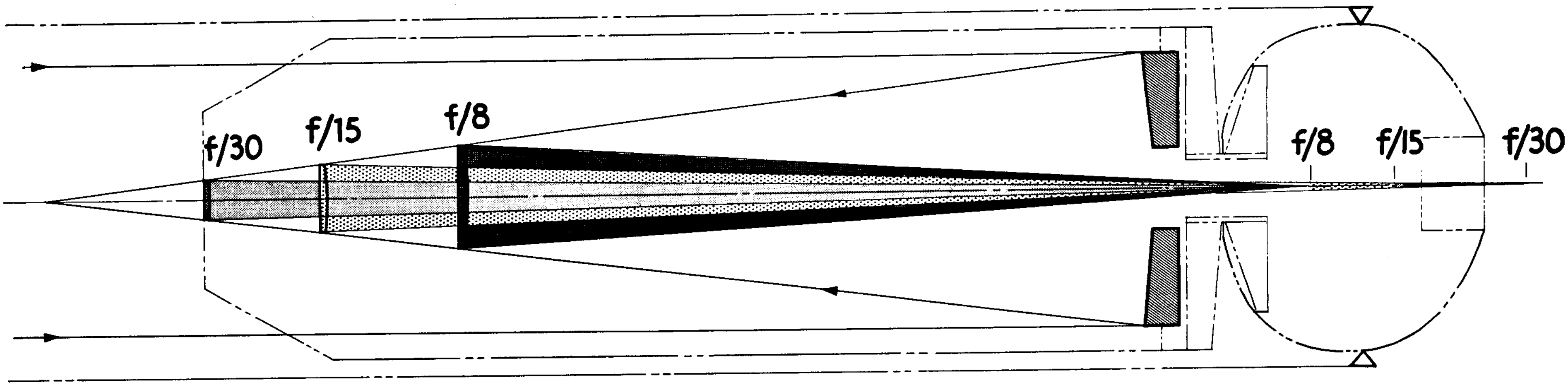
The f/8 focal plane location shown is a compromise between conflicting requirements involving telescope configuration and structural design, obscuration ratio, offset guidance requirements, and optical recording equipment at the focal plane.

This f/15 focal plane location was selected as providing adequate length in the cabin to fold the light path away from interferences of the f/8 equipment and provide room for an f/15 offset guidance package.

The indicated f/30 focal plane location was chosen to permit installation of all of the f/30 equipment at one time in such a manner that the f/30 light path could be directed to any of the several instruments by rotation of one of the folding f/30 mirrors.

Minor adjustments in the position of the f/15 and f/30 secondary mirrors are used to achieve the desired length for folding in the cabin.

OPTICAL SCHEMATIC



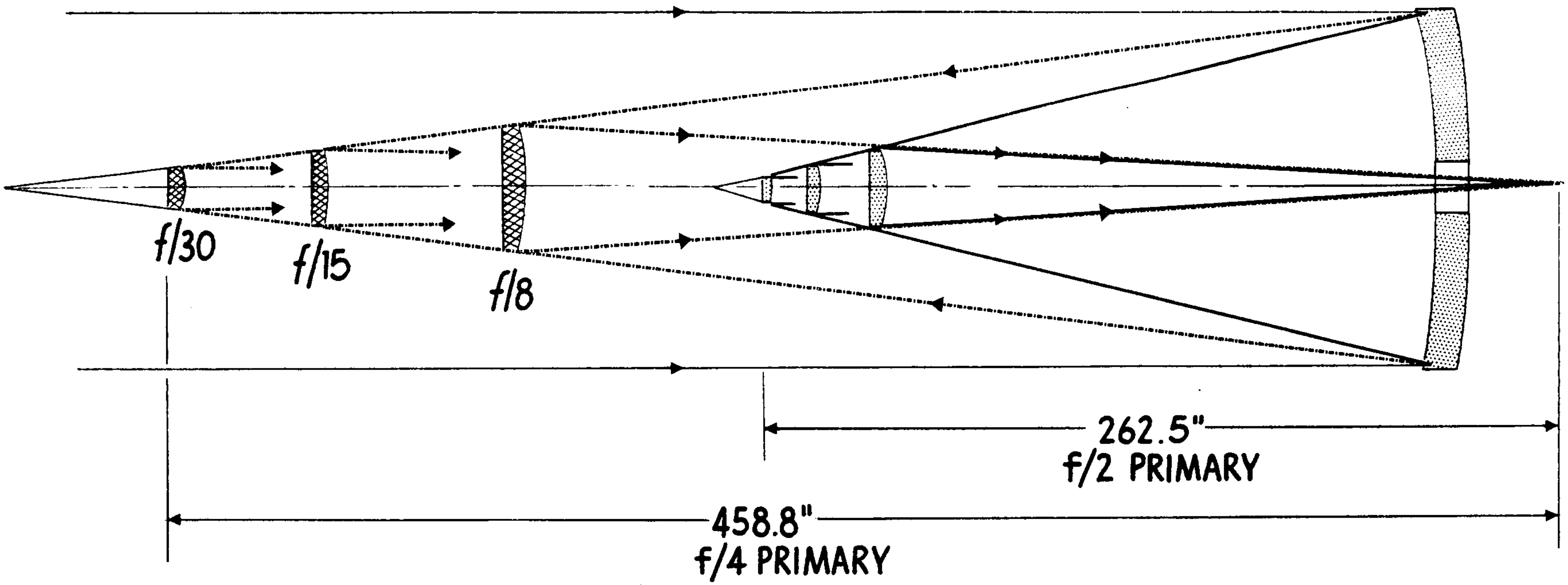
TELESCOPE OPTICS

Here we see a historical review of the consideration that has been given to various problems associated with the telescope itself.

Very early in this program it was decided that a trade study should be made to aid in the proper choice of the primary mirror focal ratio. It was assumed that the most feasible choice would fall within the f/2-f/4 range. Also, that a study based on these two focal ratios would bring out the advantages and disadvantages associated with a short and long focal length primary mirror. The schematics of both these systems are shown. The f/2 primary mirror system is shown in red and the f/4 system in green. Note that in this study the same back focal distance was used in all cases.

The selection of the primary mirror focal ratio is significant in that the magnitude of the problems in other technical areas hinge on this decision. A careless decision here may have such a snowballing effect in technical problems that the project would not appear feasible when indeed it may be. The technical disciplines necessitated by this choice are shown in the next slide.

TELESCOPE OPTICS



f/2 VERSUS f/4 PRIMARY MIRROR STUDY

Five technical areas were considered in this trade study: (1) Astronomical Observation Requirements; (2) Optical Engineering; (3) Optical Manufacture; (4) Structural Design; and, (5) Geometrical Stability.

The scientific instrumentation in the MOT would be located at a Cassegrainian equivalent focal ratio of f/8 or slower. This means the primary mirror (whether f/2 or f/4) would be used in combination with the secondary mirror to perform as though the instrumentation was at the focal plane of an f/8 primary. Therefore, optically speaking, the instruments cannot differentiate between the f/2 or the f/4 primary.

From the optical engineering standpoint, a study was made to determine the field angle performance and the optical alignment tolerances as functions of the primary mirror focal ratio. Third order aberration computations were performed with the IBM 1620 computer for a 120-inch Cassegrainian telescope using f/2, f/3, and f/4 primary mirrors and operating at equivalent focal ratios of f/8, f/15, f/30, and f/60. The conclusions of this study are presented next. *

* Saxton, J., "f/2 Versus f/4 Trade Study for the Manned Orbital Telescope," Boeing Document D2-23928-1.

f/2 VS f/4 PRIMARY MIRROR
TRADE STUDY AREAS

- OPTICAL ENGINEERING
- OPTICAL MANUFACTURING
- STRUCTURAL DESIGN
- GEOMETRICAL STABILITY

COMPARISON OF SECONDARY MIRROR POSITIONING TOLERANCES

Here we see a comparison of the positioning tolerances in regard to tilt and lateral and longitudinal displacement of the MOT secondary mirror.

At f/8 the f/4 primary system had a tilt tolerance a little over 3 times that of the f/2 system. At f/30 the f/4 system tilt tolerance was a little more than twice that of the f/2.

In lateral displacement, the tolerance was independent of equivalent focal ratio for the f/2 primary system. However, in the f/4 primary system this was not quite the case. At f/8 the tolerance was greater than the slower f/numbers. The lateral displacement tolerance is eight to ten times greater for the f/4 primary system than for the f/2 system.

The longitudinal displacement tolerance of the f/4 primary system is about four times greater than the f/2 system.

POSITIONING TOLERANCE COMPARISON

SECONDARY MIRROR

CASSEGRAINIAN EQUIVALENT FOCAL RATIO	TILT (SEC)		LATERAL DISPLACEMENT (IN)		LONGITUDINAL DISPLACEMENT (IN)	
	$f/2_p$	$f/4_p$	$f/2_p$	$f/4_p$	$f/2_p$	$f/4_p$
$f/8$	3	10	0.0008	0.009	0.00016	0.00065
$f/15$	5	13	0.0008	0.007	0.00017	0.00062
$f/30$	10	23	0.0008	0.007	0.00017	0.00064
$f/60$	19	43	0.0008	0.007	0.00017	0.00064

MANUFACTURING

There is considerable question about being able to manufacture a diffraction-limited Cassegrainian system of a much faster speed than an f/4. In fact, this was the reason for selecting an f/4 primary in the Stratoscope II system and it was a 36-inch diameter mirror.

Dr. James G. Baker was consulted about the difficulty in manufacturing the f/2 versus the f/4 primary. He pointed out that the difficulty was related to the rate of curvature change and he illustrated with a 704 computer run that the rate of change of curvature of the f/2 is 8 times that of the f/4.

This would mean smaller tools and many more operations required, as well as more zones to blend and more stringent control of pitch flow and strokes to prevent gouging and sleeks.

Dr. Baker estimates the cost of the f/2 to be three times that of the f/4 and he estimates that it would require 3 to 6 years to manufacture the f/2 compared to 1 to 3 years for the f/4.

He also stated that on an all-out "cost-doesn't count" effort, it could take about 2 to 4 years to manufacture the f/2.

The structural design and geometric stability aspects of the f/2 versus f/4 trade will be discussed in the sections on Design and Control of Optical Geometry.

f/2 VS f/4 TRADE

MANUFACTURING

- <u>FEASIBILITY</u>
  - f/2 QUESTIONABLE
  - f/4 WITHIN STATE OF THE ART
- <u>MAJOR PROBLEM - RATE OF CHANGE OF CURVATURE</u>
  - f/2 8 TIMES GREATER THAN f/4
  - f/2 SMALLER TOOL & MANY MORE OPERATIONS
  - f/2 TIGHTER CONTROL OF POLISHING PITCH FLOW RATE
- <u>DEVELOPMENT COST AND SCHEDULE</u>
  - <u>COST</u>
    - f/2 3 TIMES GREATER THAN f/4
  - <u>SCHEDULE</u>
    - 3 TO 6 YEARS FOR f/2; 1 TO 3 YEARS FOR f/4
    - ALL OUT EFFORT MAY RESULT IN AN f/2 IN 2 TO 4 YRS.

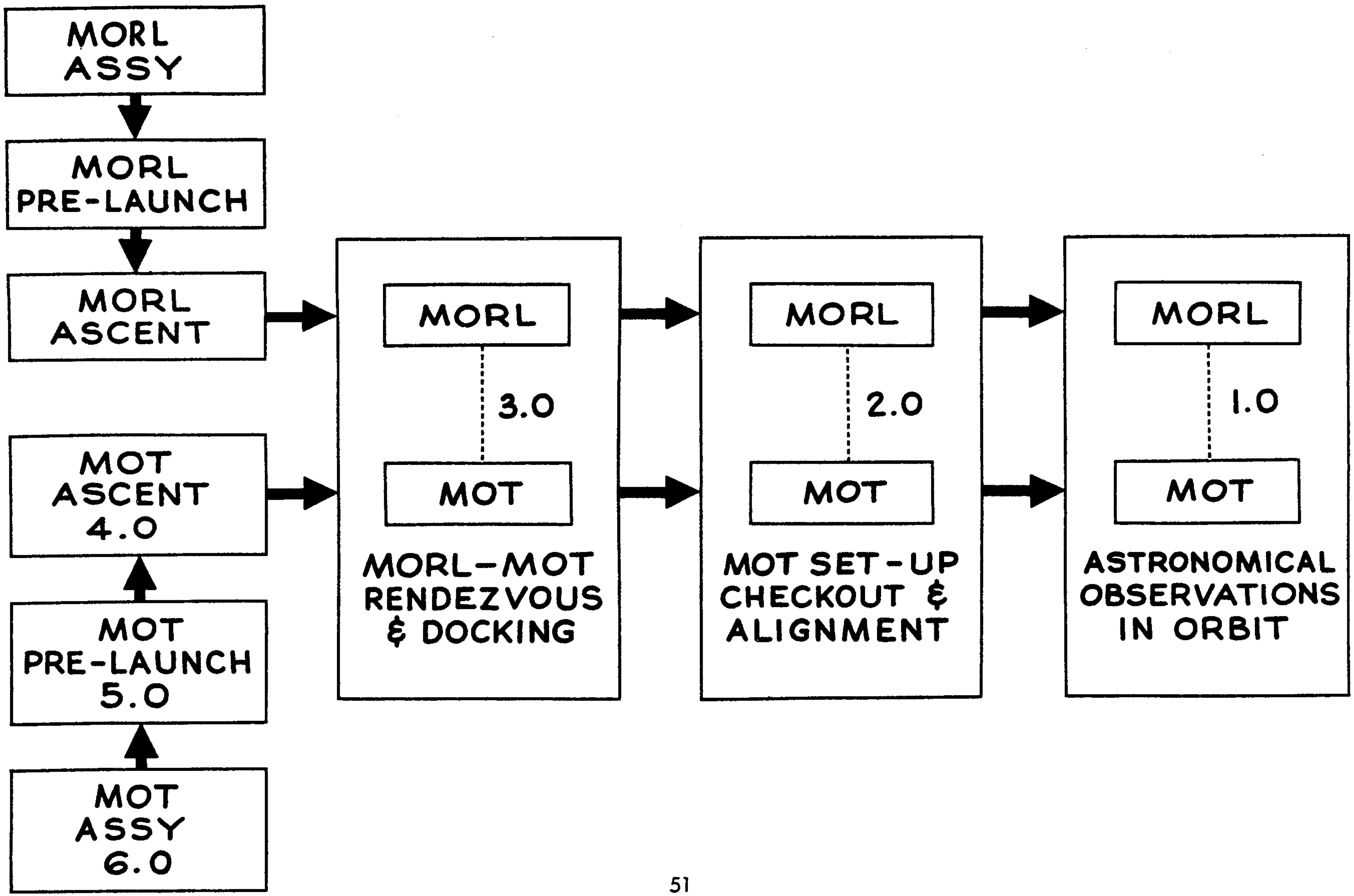
FUNCTIONAL ANALYSIS

FIRST-LEVEL FUNCTIONAL FLOW

This figure shows the first-level flow of the MOT and the interrelationships with the MORL at this level. The major functions related to the MOT are "Assembly and Checkout," "Prelaunch," "Ascent," "Rendezvous and Docking," "MOT Setup, Checkout and Alignment," and "Astronomical Observations In Orbit." The functions are numbered from 1.0 through 6.0, starting with the function which accomplishes the mission objective, Astronomical Observations In Orbit. To date, the functional analysis has taken the subfunctions of "Astronomical Observations In Orbit" through three levels of detail, and the "MOT Setup, Checkout and Alignment" subfunctions through two levels of detail.

In this section, the three levels of detail of the "Astronomical Observations In Orbit" functions are illustrated and described; and a sample of the operational requirements derived from these charts is shown. A functional description of each mode is shown.

FIRST-LEVEL FUNCTIONAL FLOW



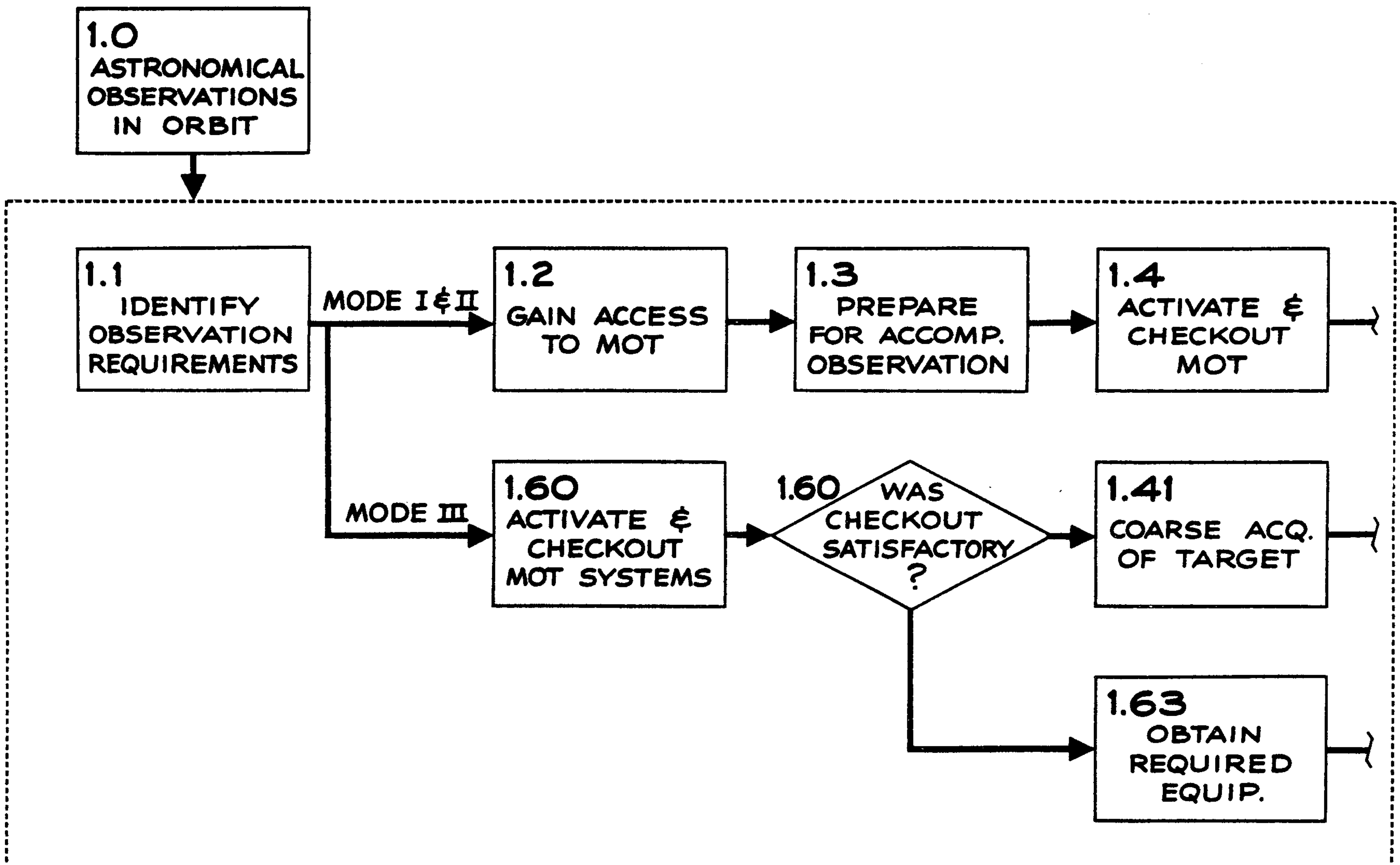
SECOND-LEVEL FUNCTIONAL FLOW

This shows the beginning of the second functional level for the "Astronomical Observations In Orbit." The major function (1.0) is shown above its subfunctions and when the analysis is carried to the next level of detail, the subfunctions of a block (such as 1.1) will be shown in the same way.

At this level differences between modes appear. The example shown is the difference between Modes I, II, and III in initiating an observation. In Modes I and II the MOT will always be entered and prepared for an observation before actually taking data; in Mode III the MOT will first be activated and checked out from the MORL, then if the checkout is not successful, astronauts will travel to the MOT for servicing or maintenance. Trips between the spacecraft will thus be kept to a minimum.

The diagram from which this figure was taken shows all functions at this level through the receipt and evaluation of the data on Earth and coordination with Earth on future observations.

SECOND-LEVEL FUNCTIONAL FLOW

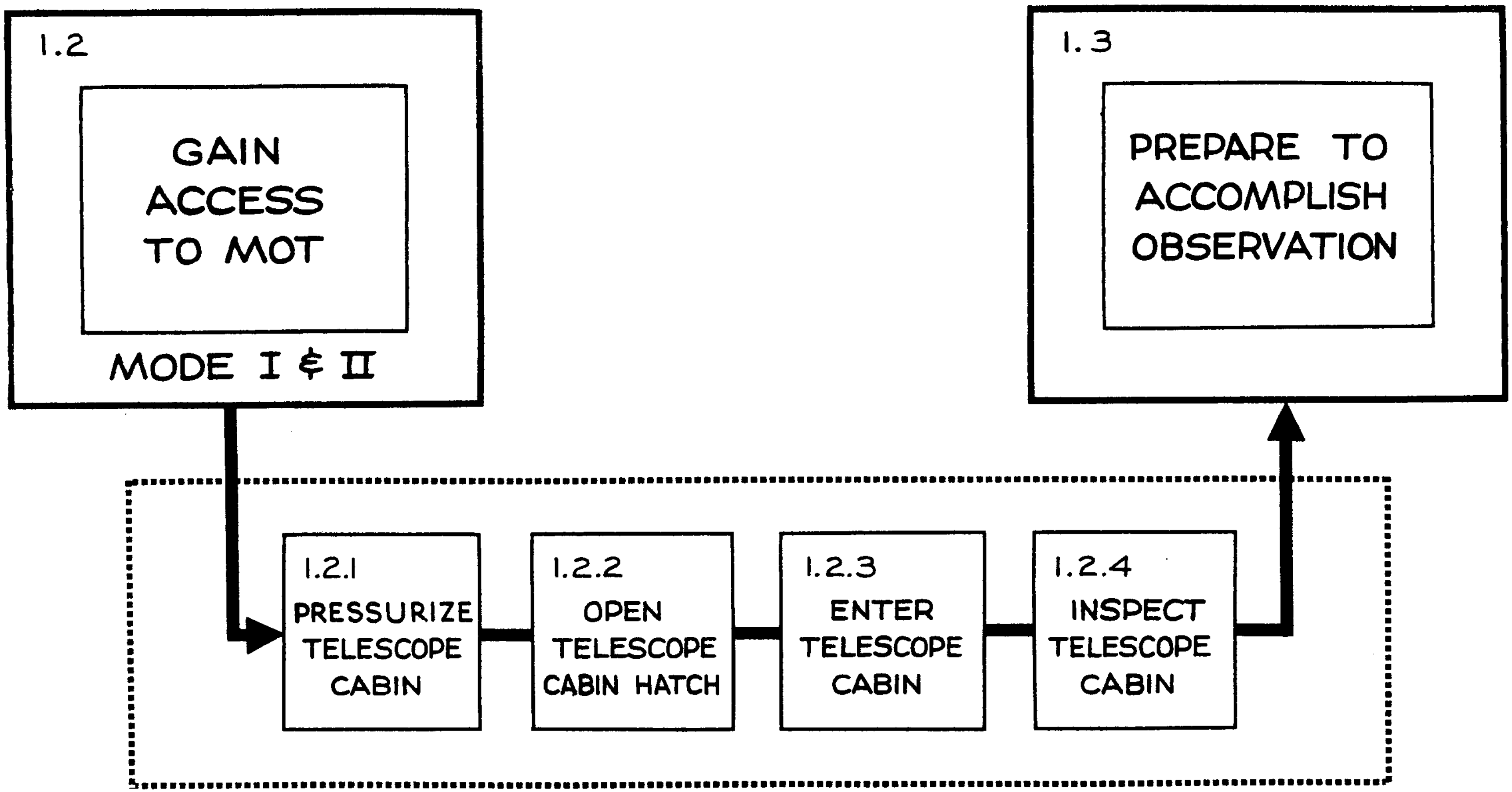


THIRD-LEVEL FUNCTIONAL FLOW

This shows the subfunctions of one of the functions shown on the second-level function diagram. The functions shown are those required to gain access to the MOT in Modes I and II.

The next step in the functional analysis process was to define the tasks required to perform each of the functions on this third level of function. Then the tasks were used to: determine the approximate number of men required to operate the MOT; determine the general skills required of these men; determine the time required for astronomical observations; and to write preliminary equipment requirements.

THIRD-LEVEL FUNCTIONAL FLOW



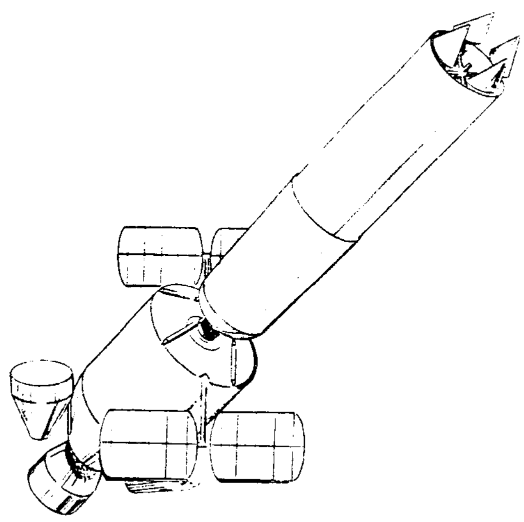
MODE IA — FUNCTIONAL DESCRIPTION

Rigid Couple

Now we will consider the eight variations of the MOT which have been studied. In Mode IA the telescope is launched separately and rendezvouses with a MORL. After docking it is permanently coupled to the laboratory and all operations are performed while it is coupled. Attitude positioning and stabilization is accomplished by positioning the entire MORL-MOT combination. Environmental control and electrical power are provided by increased MORL systems. The MOT cabin is depressurized while making observations. All orbit-keeping functions are provided by the MORL, probably requiring larger engines. All internal maintenance can be performed in a shirtsleeve environment. Extravehicular activity will be done through the MORL airlock and hatch.

MODE 1A – FUNCTIONAL DESCRIPTION
(RIGID COUPLE)

- PERMANENTLY FIXED TO MORL
- MORL PROVIDES:
  - ATTITUDE AND STABILIZATION
  - ENVIRONMENTAL CONTROL
  - ELECTRICAL POWER
  - ORBIT KEEPING



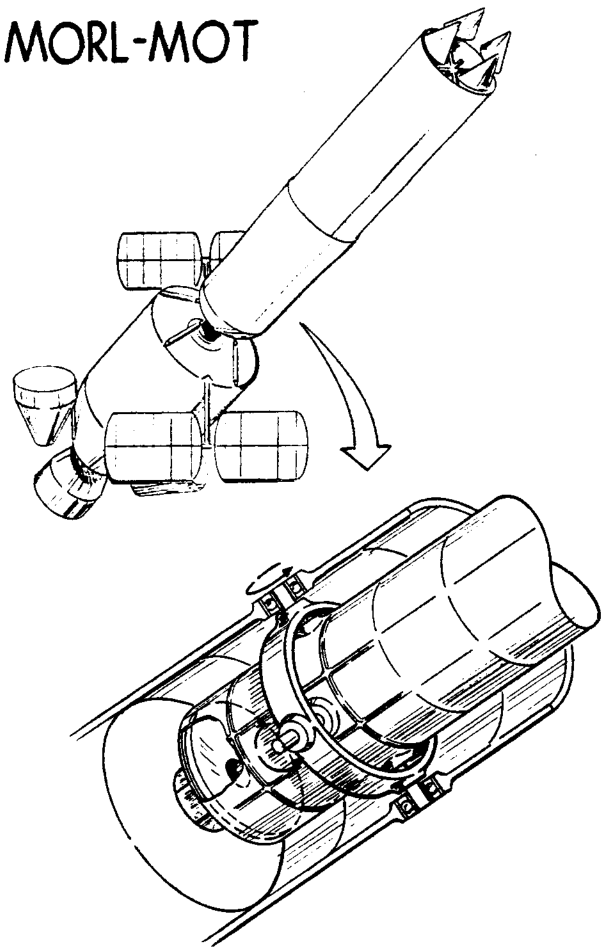
MORL-MOT

MODE IB — FUNCTIONAL DESCRIPTION

Gimbaled Couple

In this mode the rigid attachment to the MORL is retained but MORL disturbances are isolated from the telescope optical systems by using a two-axis gimbal support. The angular travel within the gimbal is limited to ± 0.5 degrees; therefore, the MORL attitude must be controlled within similar limits. For large angular changes of the telescope, the gimbals are locked and the MORL-MOT combination slewed to the desired inertial attitude. As in Mode IA, electrical power, environmental control, and orbit keeping are supplied from the MORL and internal maintenance can be performed in a shirtsleeve environment.

MODE 1B – FUNCTIONAL DESCRIPTION
(GIMBALED COUPLE)



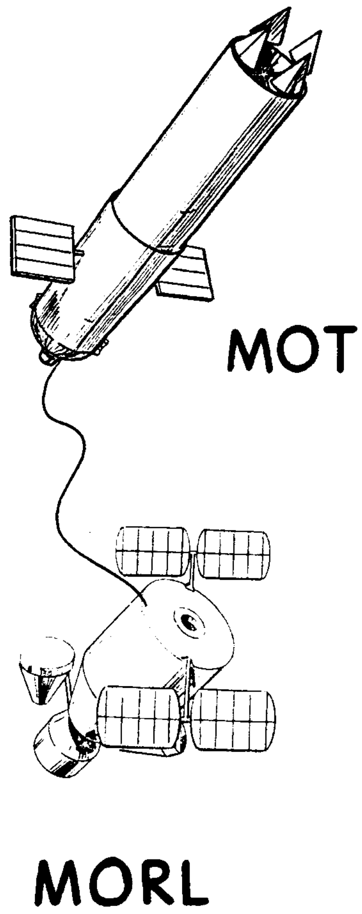
- PERMANENTLY FIXED TO MORL
- GIMBAL RANGE $\pm 0.5°$
- INDEPENDENT STABILIZATION OF OPTICS
- MORL PROVIDES:
  - ENVIRONMENTAL CONTROL
  - ELECTRICAL POWER
  - ORBIT KEEPING

MODE IIA — FUNCTIONAL DESCRIPTION

Tether

In this mode the intermittent docking concept is implemented by attaching a tether or lanyard to the MOT after it has rendezvoused and docked with the MORL. Subsequent operations consist of pre-experiment preparations accomplished in this coupled position and observations performed in the uncoupled position. The tether concept was investigated to determine possible advantages as an assistance in repetitive docking, for transmission of electrical power, for communications and data transmission, and to assist in orbit keeping. As in Modes IA and IB, electrical power, environmental control, and orbit keeping is supplied by the MORL, and internal maintenance can be done in a shirtsleeve environment.

MODE IIA-FUNCTIONAL DESCRIPTION
(TETHER)



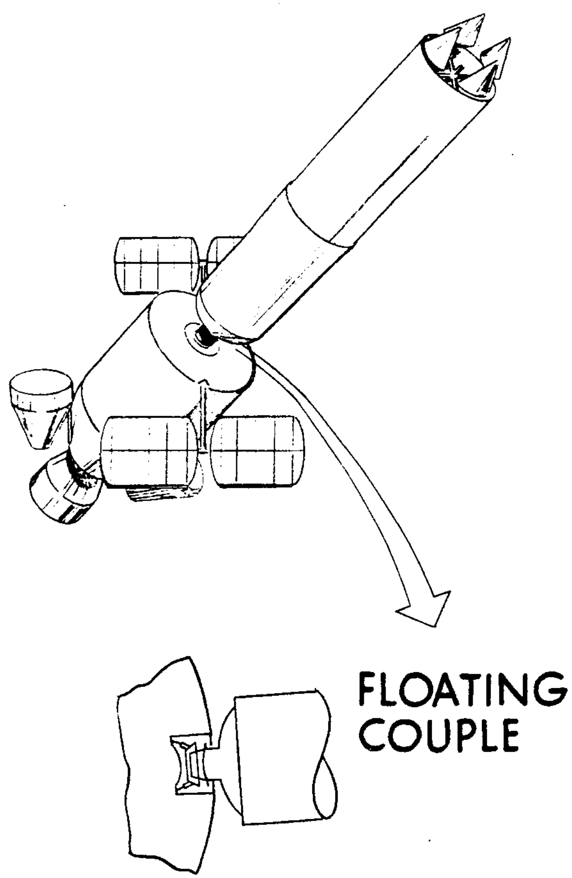
- MOT SERVICED WHILE DOCKED
- UNCOUPLED FOR OBSERVATIONS
- TETHER ASSISTS IN:
  - REPETITIVE DOCKING
  - COMMUNICATIONS
- MORL PROVIDES:
  - ENVIRONMENTAL CONTROL
  - ELECTRICAL POWER WHEN DOCKED
  - ORBIT KEEPING

MODE IIB — FUNCTIONAL DESCRIPTION

Floating Socket

In this mode the intermittent coupling is implemented by an initial docking with the MORL as in Mode IIA and then by utilizing a floating socket mechanism for subsequent coupling and uncoupling of the MOT. The floating socket mechanism permits complete separation from the MORL disturbances during observations but prevents separation beyond the confines of the socket. During observations the MORL is maneuvered to stay clear of the telescope, thus becoming enslaved to the telescope orientation. Large angular changes in MOT attitude are made by the MORL while coupled. Electrical power is supplied by batteries which are charged by the MORL when in the coupled position. Environmental control is supplied by the MORL and orbit keeping is provided by the MORL while coupled to the MOT, thus internal maintenance can be performed in a shirtsleeve environment.

MODE IIB - FUNCTIONAL DESCRIPTION
(FLOATING SOCKET)



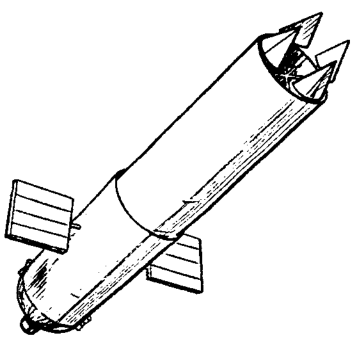
- MOT SERVICED WHILE COUPLED
- UNCOUPLED FOR OBSERVATIONS
- MOT INDEPENDENT WITHIN SOCKET
- MORL MANEUVERS TO CLEAR MOT
- BATTERY SUPPLIED POWER
- MORL PROVIDES:
  - ENVIRONMENTAL CONTROL
  - RECHARGING OF BATTERIES
  - LARGE ATTITUDE CHANGES
  - ORBIT KEEPING

MODE IIC — FUNCTIONAL DESCRIPTION

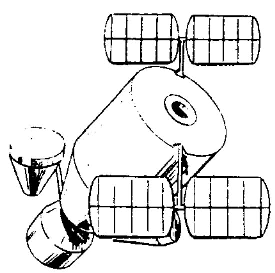
Remotely Controlled Docking

In this mode the MOT is completely uncoupled from the MORL with no physical restrictions to limit the amount of separation distance possible after uncoupling. The maneuvering system used for initial rendezvous and docking with the MORL is also used for repetitive docking after observations. The MORL provides electrical power, environmental control, and orbit keeping for the MOT while coupled. While uncoupled, the MOT attitude and stabilization and electric power is independent. All internal maintenance can be performed in a shirtsleeve environment.

MODE IIC - FUNCTIONAL DESCRIPTION
(REMOTELY CONTROLLED DOCKING)



- MOT SERVICED WHILE DOCKED
- UNCOUPLED FOR OBSERVATIONS
- INDEPENDENT ATTITUDE, STABILIZATION & MANEUVERING SYSTEMS
- MORL PROVIDES:
  - ENVIRONMENTAL CONTROL
  - ELECTRICAL POWER WHILE DOCKED
  - ORBIT KEEPING WHILE DOCKED



MODES IIIA AND B — FUNCTIONAL DESCRIPTION

MORL and MOT Separate — Travel In Spacesuit

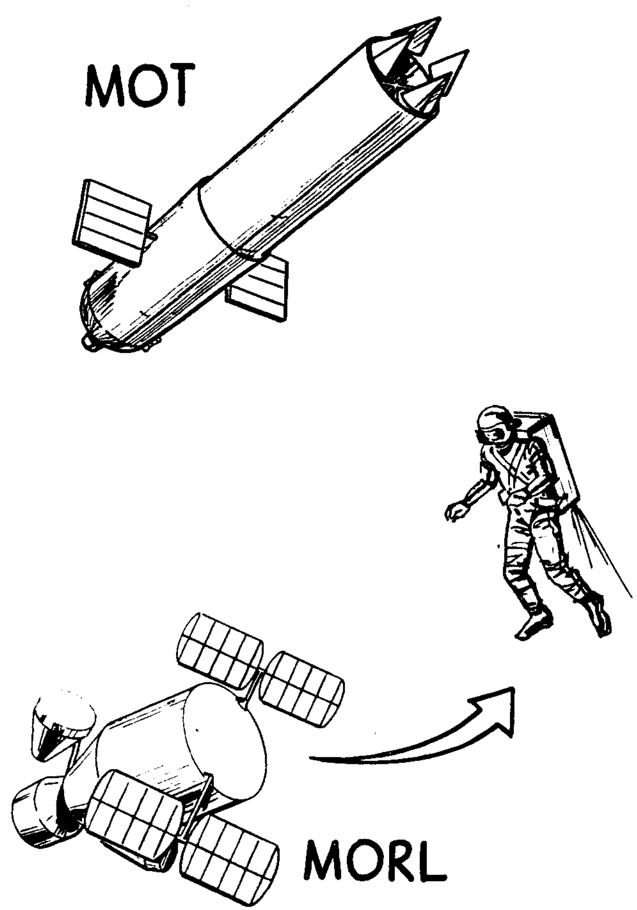
MODE IIIA — UNPRESSURIZED CABIN

In this mode the MOT rendezvouses with the MORL but never docks. It is operated close to the MORL and man travels to and from the MOT and performs all functions in a pressurized spacesuit. The MOT has its own electrical power and orbit-keeping systems. Environmental control consists only of thermal control for the cabin; life support requirements are provided by the spacesuit portable life support systems. Internal maintenance must be performed in the pressurized spacesuit.

MODE IIIB — PRESSURIZED CABIN

This mode is essentially the same as Mode IIIA except that a complete environmental control system is provided for the cabin. Maintenance is performed in the cabin in the depressurized spacesuit and, as in Mode IIIA, man must still travel to the MOT in a spacesuit and transport all required equipment with him.

MODES IIIA & B - FUNCTIONAL DESCRIPTION
(MORL & MOT SEPARATE - ASTRONAUT TRANSFER)



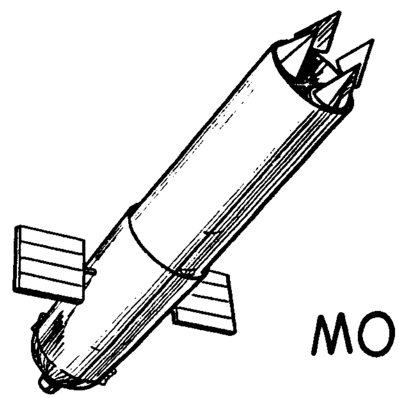
- NEVER DOCKED
- TRAVEL IN SPACE SUIT
- INDEPENDENT SUBSYSTEMS
  - ENVIRONMENTAL CONTROL
  - ELECTRICAL POWER
  - STABILIZATION
  - ORBIT KEEPING
- IIIA - NO PRESSURIZED CABIN
- IIIB - PRESSURIZED CABIN

MODE IIIC — FUNCTIONAL DESCRIPTION

MORL and MOT Separate — Travel By Shuttle

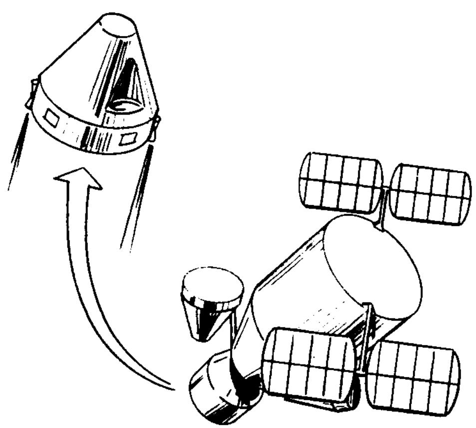
In this mode the MOT remains in the vicinity of the MORL and man utilizes a shuttle vehicle for transferring to and from the MOT and for transporting required equipment. The shuttle vehicle provides a shirtsleeve environment for man during the transfer and also provides cabin pressurization for the MOT while the shuttle is docked. Orbit keeping of the MOT is also provided by the shuttle. The MOT has its own electrical power and thermal control systems for the cabin. Internal maintenance can be performed in a shirtsleeve environment.

MODE IIIC - FUNCTIONAL DESCRIPTION
(MORL & MOT SEPARATE — TRAVEL BY SHUTTLE)



MOT

- NEVER DOCKED
- TRAVEL BY SHUTTLE
- INDEPENDENT SUBSYSTEMS
  - ELCTRICAL POWER
  - THERMAL CONTROL
  - STABILIZATION



MORL

- SHUTTLE PROVIDES:
  - ENVIRONMENTAL CONTROL
  - ORBIT KEEPING
  - SHIRTSLEEVE TRANSFER

ROLE OF MAN

ROLE OF MAN

The preliminary definition of man's role has been divided into five general categories. The first involves the initial activation of the MOT preparatory to beginning observations. This involves making changes from launch configuration to orbital configuration, adjusting and aligning the optical elements, and activation and checkout of the subsystems.

The next category is experiment control which is man's direct role in orbit in accomplishing the desired observations. This involves pre-experimental preparation, setup and checkout of the particular piece of optical auxiliary equipment for a given type of observation. Also involved are man's activities from the MORL in monitoring and remotely controlling the MOT during the observation.

The third category of man's activity is concerned with data retrieval, processing, and gross evaluation of general data quality.

The fourth area of man's role is overall program monitoring and it encompasses all of the management aspects of the MOT system in orbit. Man's activities in this area involve remotely or directly monitoring all systems and equipment of the MOT, communications with ground-based stations for possible changes in the observation program, and ensuring that the MOT/MORL interfaces function properly.

The last category of man's role involves periodic inspection and servicing of the MOT and performance of any necessary unscheduled maintenance.

ROLE OF MAN

- INITIAL SETUP, CHECKOUT, ALIGNMENT
- EXPERIMENT CONTROL
- DATA INTERPRETATION & PROCESSING
- OVERALL PROGRAM MONITORING
- MAINTENANCE

ROLE OF MAN

Initial Setup, Checkout, and Alignment

After rendezvous with the MORL the crew must set up the telescope in its orbital configuration. The highly critical nature of the optical elements requires that special supports and restraints be used to withstand the severe boost environment. These supports must be removed in orbit and orbital supports attached to achieve the highly accurate positioning required.

Optical checkout and alignment must be accomplished with the telescope at operational temperature and in thermal equilibrium. This may require both manual adjustments and the use of servo systems.

It will be necessary to activate and check out the thermal control system. Details of this system are not presently known, but the system will probably require some active elements. The optical auxiliary equipment and the instrument support base must be kept at relatively stable temperatures to maintain alignment during observations.

Setup of the optical auxiliary equipment in the cabin will be required initially as well as periodically throughout the observational program. Provisions may be required for shock isolation of the optical auxiliaries during launch with subsequent attachment to the instrument base and adjustment in orbit.

The various other subsystems of the MOT such as electrical power, communications, stabilization and control, etc., must be activated and checked out before beginning observations.

ROLE OF MAN

INITIAL SETUP, CHECK OUT, & ALIGNMENT

- REMOVE LAUNCH-SUPPORT STRUCTURE
- ATTACH ORBITAL SUPPORTS FOR SENSITIVE OPTICAL ELEMENTS
- PERFORM OPTICAL ALIGNMENT
- ACTIVATE & CHECK OUT THERMAL CONTROL SYSTEM
- SETUP & CHECK OUT AUXILLIARY OPTICAL EQUIPMENT
- ACTIVATE & CHECK OUT REMAINING SUBSYSTEMS

ROLE OF MAN

Experiment Control

Experiment control is defined here as man's direct role in orbit in accomplishing the objectives of the required observations. This includes setup of the required system focal ratio and preparation of the appropriate instruments. Manual operations will probably be required in the MOT in conjunction with remote operations from the MORL. A man in the MOT cabin may be required to monitor and verify that remote commands have functioned properly. In some cases adjustments will probably be required by man in the MOT.

Remote operations from the MORL will include monitoring of star patterns using a video link. In some cases it may be desirable to manually slew the telescope to a target star for acquisition by the fine-guidance sensor.

Other activities in experiment control will involve monitoring to ensure that the telescope remains in focus, making sure that exposure times are compatible with light readings, checking the stabilization system, and ensuring that the thermal balance of the telescope remains within prescribed limits.

Direct control functions include remotely advancing the photographic film or changing plates, changing filters, setting timers, or indexing the movable folding mirror for use of a different instrument.

The equipment used to record outputs from photoelectric detectors must be monitored for proper signal levels and turned on and off at the proper times.

ROLE OF MAN

EXPERIMENT CONTROL

- PRE-EXPERIMENT PREPARATION
  - MANUAL OPERATIONS IN MOT-EQUIPMENT SETUP
  - REMOTE OPERATIONS FROM MORL
  - VERIFICATION OR ADJUSTMENT IN MOT
- MONITOR STAR PATTERN USING VIDEO LINK
- MANUAL SLEW CAPABILITY FOR GROSS ORIENTATION
- MONITOR FOCUS, EXPOSURE READING, STABILITY, THERMAL CONTROL, ETC.
- REMOTELY ADVANCE FILM AND CHANGE FILTERS, EXPOSURE TIMES, OR RECORDING EQUIPMENT
- MONITOR RECORDING-EQUIPMENT SIGNAL LEVERS

ROLE OF MAN

Data Interpretation and Processing

Man's role in this area includes all activities involved in manually obtaining the observational data from the MOT and delivering it to the ground. Present concepts involve retrieval of photographic plates and film packages from the MOT cabin, transfer to the MORL for processing and rough evaluation, and preparation for return to the ground either by data capsule or by ferry vehicle.

Man's role in examination of negatives will depend on the skill levels finally selected, but would at least consist of evaluating the general quality and determining if the experiment must be repeated. In some cases, enlargements of selected areas may be desirable for transmittal to the ground for "quick-look" purposes.

The use of data capsules is one way of returning photographic plates and film to the ground earlier than would be practical using ferry vehicles.

ROLE OF MAN

DATA INTERPRETATION & PROCESSING

- MANUAL REMOVAL OF PHOTOGRAPHIC PLATES & FILM PACKAGES
- PLATE & FILM DEVELOPING IN MORL
- EXAMINE NEGATIVES & EVALUATE QUALITY
- MAKE ENLARGEMENTS OF SELECTED AREAS
- TRANSMIT PORTIONS OF IMAGES TO GROUND FOR "QUICK-LOOK"
- PREPARE DATA FOR RETURN TO GROUND
    - DATA CAPSULE
    - FERRY VEHICLE

ROLE OF MAN

Overall Program Monitoring

Man's role in overall program monitoring is primarily that of an orbital operations manager, and covers all aspects of the total MOT system. Overall program direction will be provided from the ground where teams of highly specialized astronomers can study in detail and evaluate the various data that is received. A preplanned observational program will be used at least initially in the MOT operations. As data is gathered and examined, it is expected that some observations will be repeated, with different equipment settings, and specialized areas of interest will be examined. Flexibility in operational procedure appears to be a very important criterion in the MOT design.

Man's role in orbit would involve communications with ground control and implementation of the required changes in the observational plan. His role as an orbital operations manager may also require on-the-spot changes in telescope operation because of equipment malfunction.

His primary task in this area is to manage telescope usage to achieve the desired observations with maximum efficiency.

The task of monitoring the MOT for proper operation, performing periodic inspections, and performing unscheduled maintenance are all part of keeping the telescope operating efficiently.

ROLE OF MAN

OVERALL PROGRAM MONITORING

- ORBITAL OPERATIONS MANAGER
  - OVERALL PROGRAM DIRECTION FROM GROUND
  - PREPLANNED OBSERVATION PROGRAM
  - PROGRAM CHANGES FOR TECHNICAL REASONS
  - MANAGE ORBITAL OPERATIONS FOR MAXIMUM EFFICIENCY
- REMOTELY MONITOR MOT FOR PROPER OPERATION
- PERFORM PERIODIC INSPECTIONS & CHECKOUT
- PERFORM UNSCHEDULED MAINTENANCE

ROLE OF MAN

Maintenance

The ability of man to maintain the MOT in orbit is essential to the success of the 3-year mission. Maintenance in orbit is the only way a satisfactory system reliability will be achieved. This maintenance capability must encompass all areas of the telescope, both in the cabin and extravehicularly in the telescope proper.

To facilitate maintenance in orbit, modular packaging should be used, where possible, for all subsystems and equipment. Techniques for fault isolation to the smallest replaceable module are necessary so that man can replace the failed part with a spare.

Careful attention must be given to the design of the MOT for the limitations of man in the pressurized spacesuit. Good accessibility is required and fasteners should be sized and designed for handling with the pressurized gloves. Means for captivating bolts and nuts, as well as tethers or retainers for small parts, will be necessary. Special tools may be required for special applications.

Special-purpose restraint and locomotion devices for man in the zero-g environment may be highly desirable to reduce the difficulty and time required for maintenance. This may be especially true of maintenance in the pressurized spacesuit.

ROLE OF MAN

MAINTENANCE

- MODULAR PACKAGING FOR ALL SUBSYSTEMS AND EQUIPMENT
- FAULT ISOLATION TO SMALLEST REPLACE-ABLE MODULE
- REPLACE FAILED PART WITH SPARE
- DESIGN FOR MAINTENANCE BY ASTRONAUT IN PRESSURIZED SPACESUIT
    - FASTENERS SIZED & DESIGNED FOR HANDLING WITH PRESSURIZED GLOVE
    - CAPTIVATED DEVICES
    - SPECIAL TOOLS
    - SPECIAL-PURPOSE RESTRAINT AND LOCOMOTION DEVICES

ROLE OF MAN

Restraint and Positioning Device

The zero-g restraint and positioning device illustrated represents one concept for special-purpose equipment, which would provide reaction points for applied torques and would aid man in performing extravehicular maintenance functions. It consists of a lightweight seat and stirrup restraint which is mounted on a telescoping arm. The telescoping arm has two pivots and is mounted in a 360-degree track.

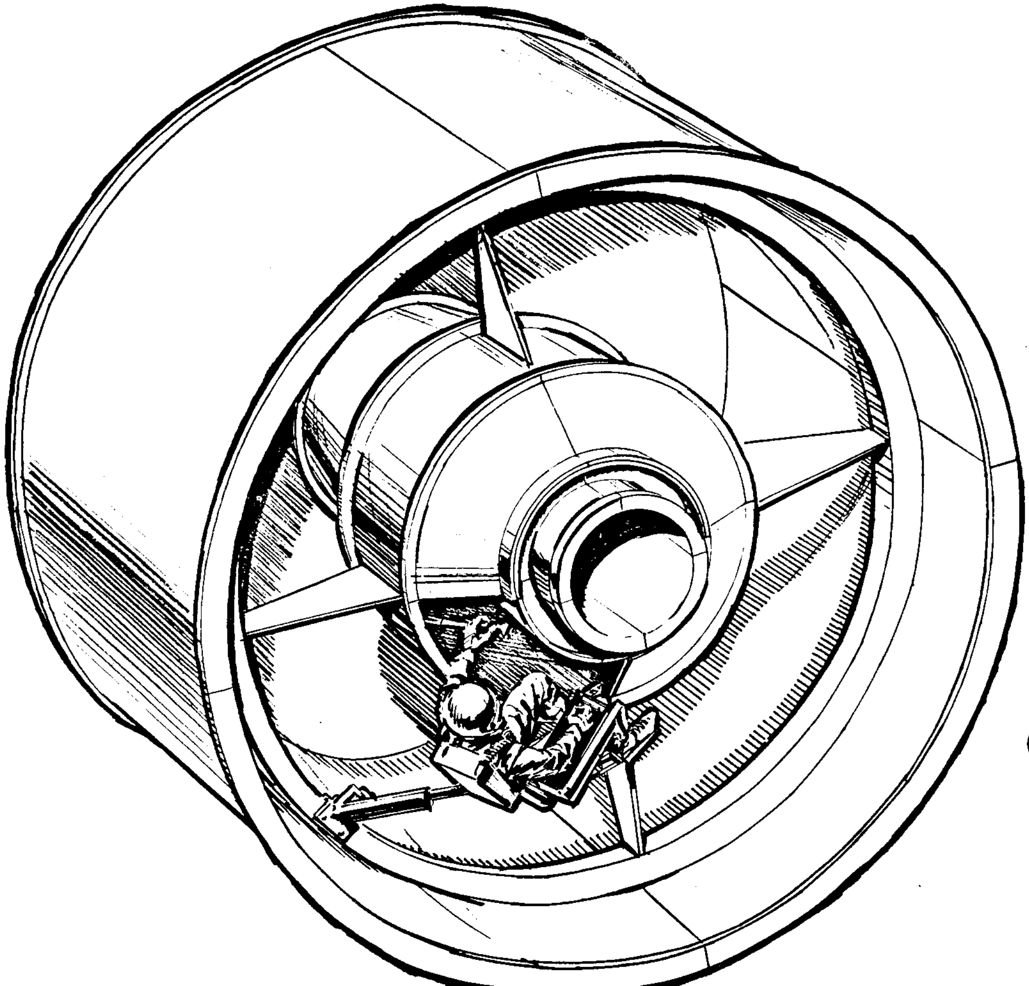
Electric motors with conveniently located slewing switches would be used to move the man in a wide range of positions and attitudes. Four degrees of freedom are provided and the unit could be locked in any desired position.

Attachments such as containers for tools, spare parts, and other maintenance items could be attached to the side of the seat. This restraint and positioning device would be removable for repair or replacement and could be stowed out of the optical path when not in use.

In the zero-g environment the loading on the telescoping arm and mounting track would be the product of man's applied force and the distance to the attachment. Translation movements can be held to a moderate rate to minimize man's inertial forces.

Such a restraint and positioning device as described here could aid substantially in improving maintenance capability and reducing maintenance time.

RESTRAINT & POSITIONING DEVICE



- LIGHTWEIGHT & STOWABLE
- PROVIDES REACTION POINTS
- ELECTRIC -MOTOR DRIVEN
- FOUR DEGREES OF FREEDOM
- FACILITATES TOOL & PART HANDLING
- REMOVABLE
- IMPROVED MAINTENANCE

ROLE OF MAN

MORL Activities

Man's activities in the MORL will be of three general types. First, there is a requirement to monitor the operation of the MOT, its subsystems and equipment, and the astronomical experiment. Secondly, there are control functions which must be accomplished remote from the MORL. The third type of activity is data handling.

The MOT must have suitable instrumentation so that man can remotely monitor critical systems and conditions from the MORL. Steady-state and differential temperatures are examples of critical parameters. Subsystems such as malfunction detection, stability and control, recording, and telemetry are essential for proper operation of the telescope. It is also necessary to be able to monitor the star field and evaluate gross data quality.

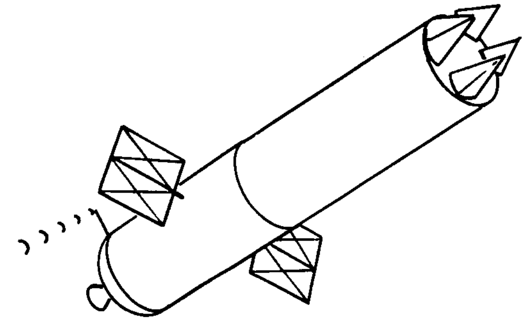
The remote control functions which man must be able to perform from the MORL include slewing the MOT to various inertial attitudes and remotely initiating experiment changes. The latter could involve controlling the position of a folding mirror in the cabin, advancing the film or plates in a camera, or setting a timer for the appropriate exposure times.

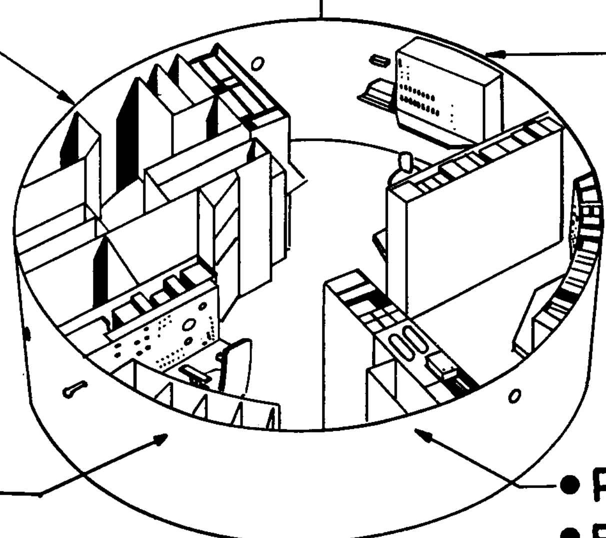
Data handling activities in the MORL include processing exposed film and plates, examination of negatives, and preparation of data capsules for return to Earth. MORL-to-Earth communications are obviously necessary and will be used for transmitting certain types of data to Earth.

ROLE OF MAN
MORL ACTIVITIES

MONITOR CRITICAL SYSTEMS

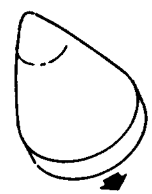
TEMPERATURES
MALFUNCTION DETECTION
STABILITY & CONTROL
RECORDING EQUIPMENT
TELEMETRY
GROSS DATA QUALITY





CONTROL FUNCTIONS

SLEW TELESCOPE
INITIATE EXPERIMENT CHANGES



DATA RETURN

- PROCESSING FILMS AND PLATES
- EXAMINE NEGATIVES & PREPARE DATA CAPSULES
- MORL-TO-EARTH COMMUNICATIONS

ROLE OF MAN

MOT Cabin Activities

One of man's primary tasks in the telescope cabin is to retrieve exposed photographic film and plates and install replacement film or plate modules. This requirement exists for stellar and planetary photography, and for film recording of high-dispersion and low-dispersion spectra. All photographic film and plates will be returned to the MORL for processing.

Other tasks in the cabin involve changing the setup of optical auxiliary equipment for operation of the telescope at the three equivalent focal ratios (f/8, f/15, and f/30). With the present preliminary design of the cabin, all of the optical equipment cannot be permanently installed and operated at each of the f/numbers because of interferences of the required optical paths. This condition may be somewhat improved with further design, or the cabin size may be increased, which would simplify the packaging problem.

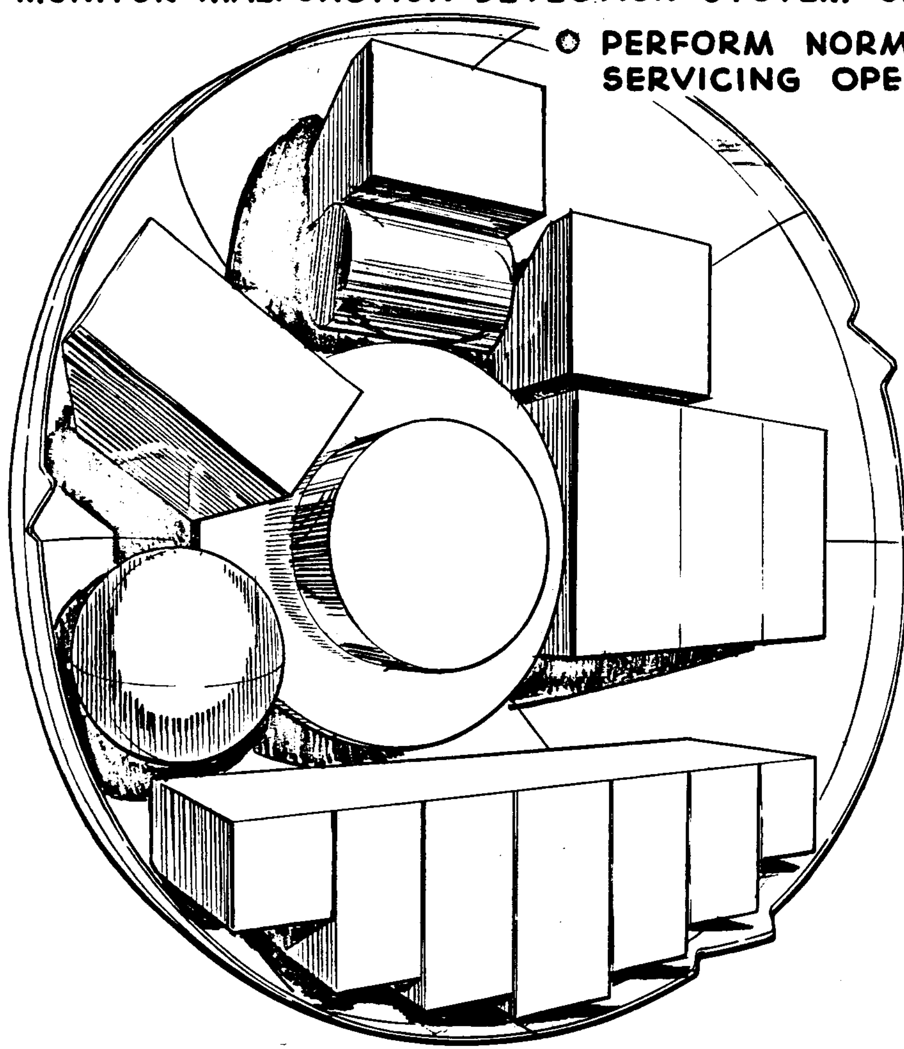
Alignment checks will be required periodically for the optical auxiliary equipment and the folding mirrors.

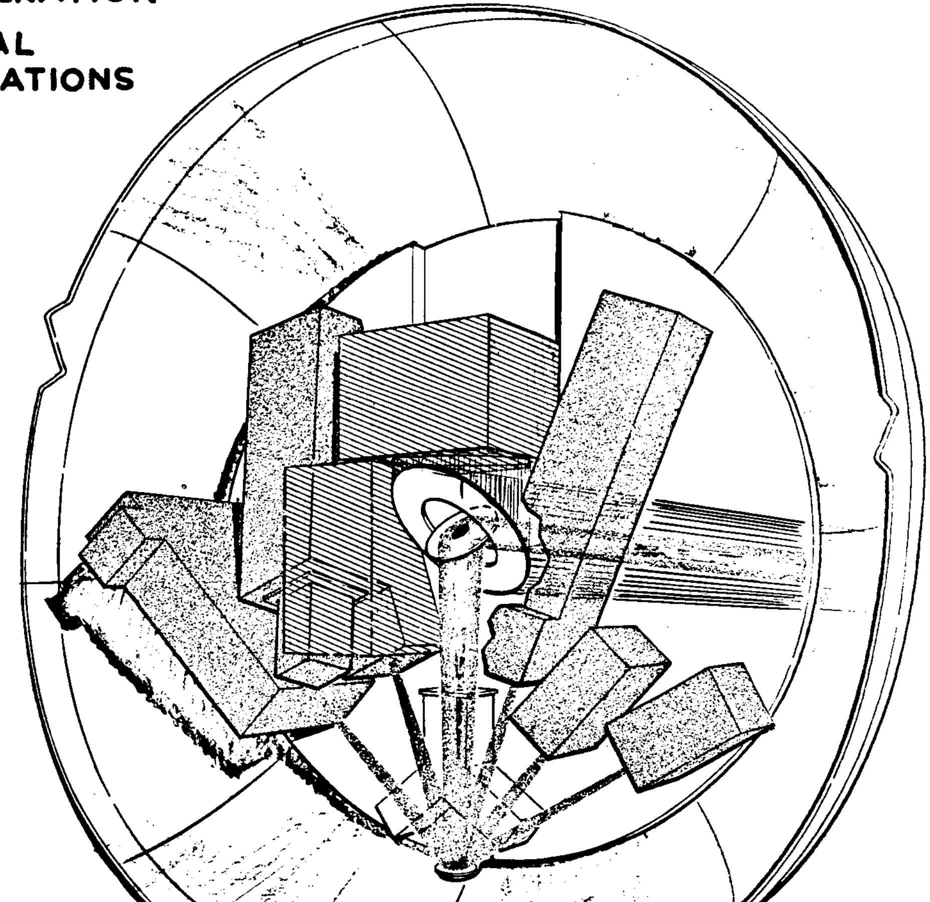
Other tasks in the MOT cabin involve monitoring the thermal control system, malfunction detection system, and other subsystems for proper operation.

Normal servicing functions in the cabin include installation or regulation of coolant for the photoelectric sensors, adjustments of the optical elements, changes in filters and apertures, and functional checks of the recording equipment.

ROLE OF MAN
MOT CABIN ACTIVITIES

- MONITOR THERMAL CONTROL SYSTEM OPERATION
- MONITOR MALFUNCTION DETECTION SYSTEM OPERATION
- PERFORM NORMAL SERVICING OPERATIONS





- RETRIEVE EXPOSED PHOTOGRAPHIC FILM & PLATES
- REPLACE FILM & PLATES
- CHANGE OPTICAL EXPERIMENTS
- PERFORM OPTICAL ALIGNMENT CHECK

ROLE OF MAN

Extravehicular Activities

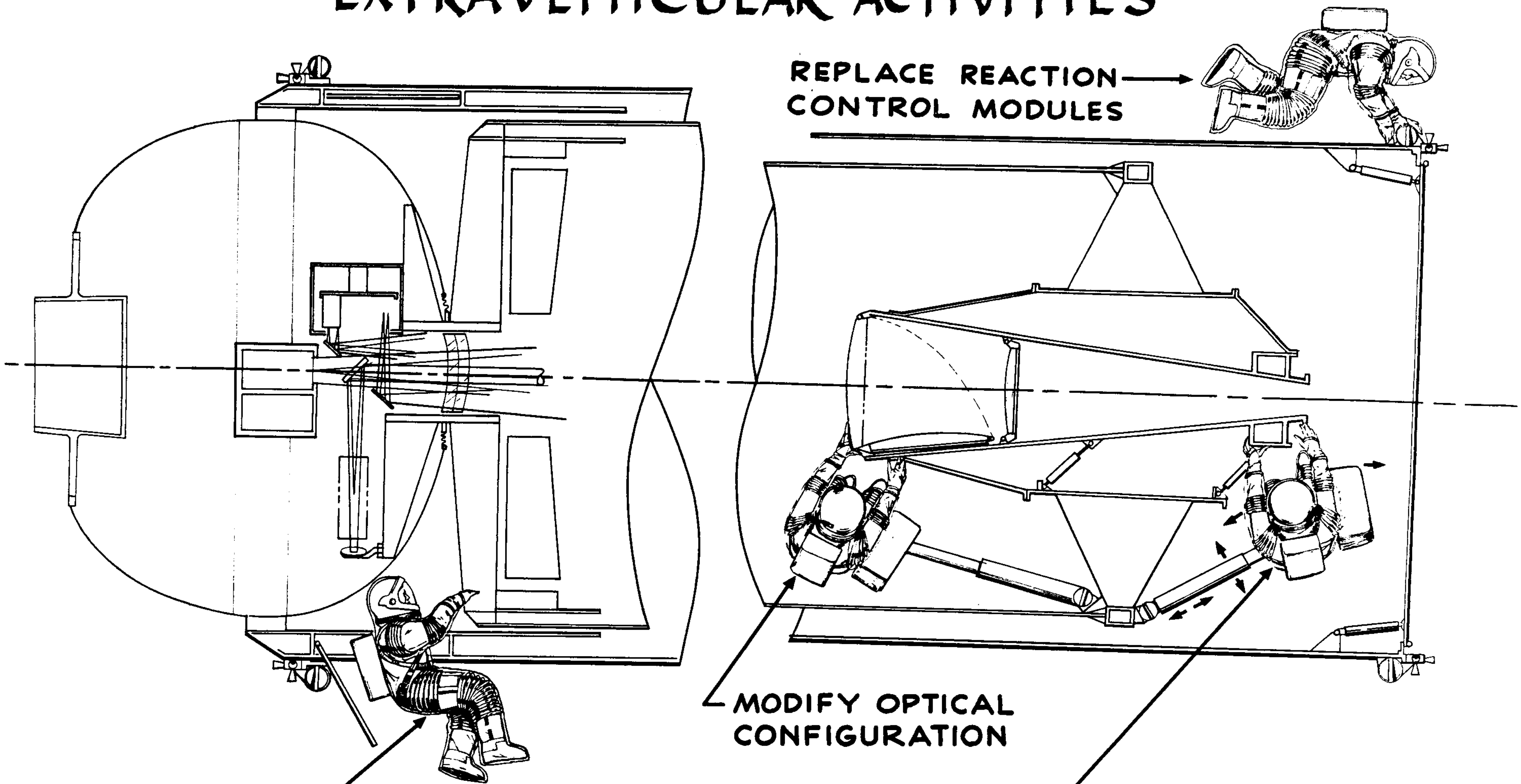
Man's activities in the pressurized spacesuit are required for initial telescope activation, maintenance outside the telescope cabin, and for changing from one secondary mirror to another.

Man's role in initial setup of the telescope in orbit requires that he work outside the vehicle to remove launch-support structure used for protecting the sensitive optical elements during the severe boost environment. Attachment of the orbital supports must be made and adjustments will probably be required for alignment. Required functions will be automated wherever practical; however, it appears that judicious use of man's capabilities could simplify the design and add to the reliability of the system.

Maintenance will be required of man in the pressurized suit in the area of the secondary mirrors. Maintenance of the door actuators will probably be required and the reaction control modules must be periodically replaced.

Changing from the use of one system f/number to another requires that a different secondary mirror be used. This function will be automatic if possible, but man may be required. Periodic inspection and checkout of the equipment in this area appears desirable.

ROLE OF MAN
EXTRAVEHICULAR ACTIVITIES



ESSENTIAL ROLE OF MAN

While many of man's activities in the telescope operations are highly desirable, there are three functions that appear essential at the present time. These functions are initial telescope setup, installation, and retrieval of film packages, and unforeseen maintenance.

It is unlikely that the MOT could be constructed so that it could be aligned prior to launch, withstand the severe launch environment, adjust to the extreme conditions of the space environment, and, at equilibrium conditions, be properly aligned and ready for observations. It is possible to automatically make the changeover from launch conditions to orbit conditions, but the complexity would greatly reduce the reliability. Failure of the automatic system would then require maintenance by man.

Man's role in retrieval of film and plates also is essential if the system is to remain practical from a size, weight, and complexity standpoint.

Provisions for performing unforeseen maintenance are obviously essential if the telescope is to have a 3- to 5-year life.

ESSENTIAL ROLE OF MAN

- INITIAL TELESCOPE SETUP
- RETRIEVE FILM & PLATES
- UNFORESEEN MAINTENANCE

ROLE OF MAN

Typical Timeline Analysis

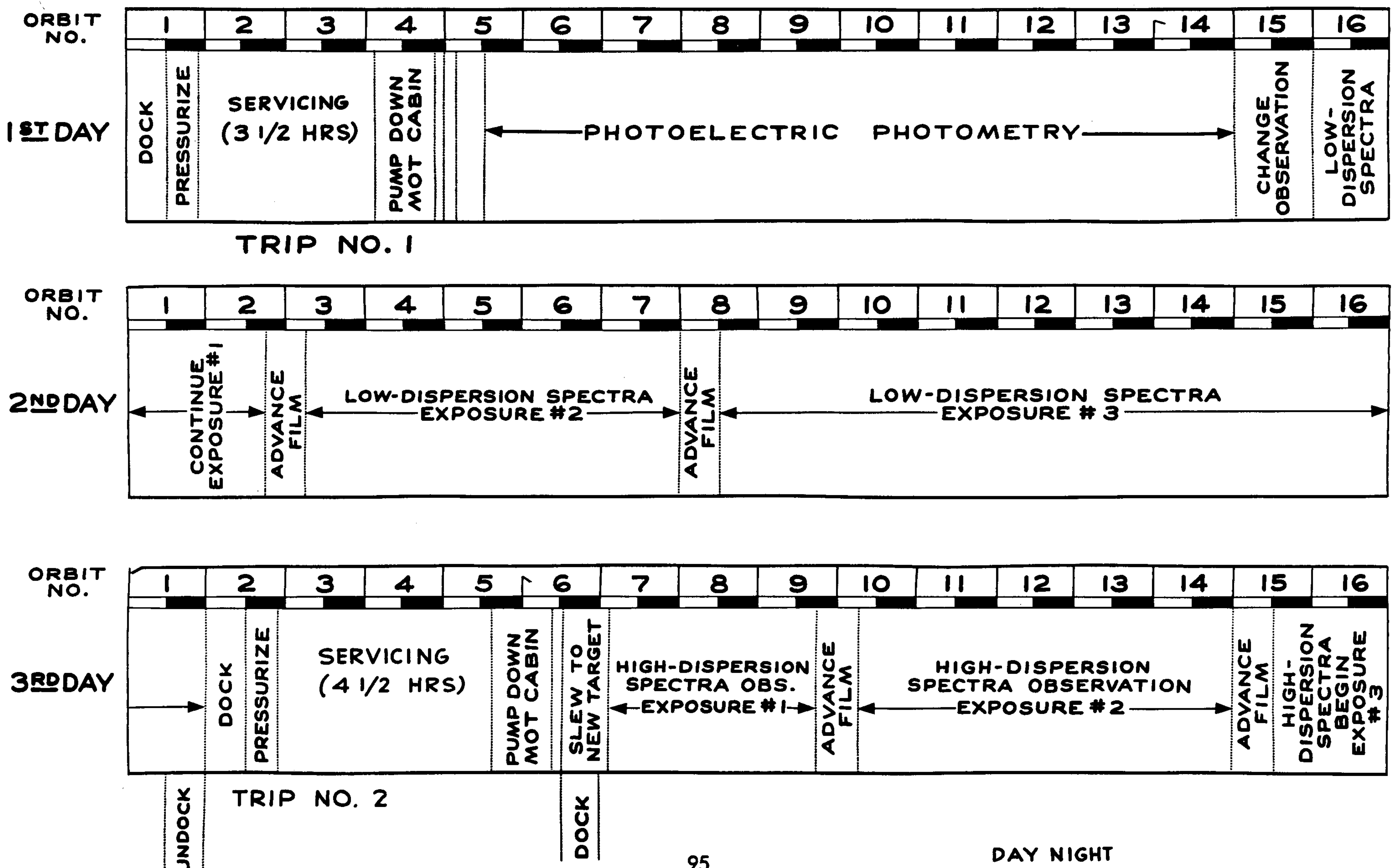
To assist in selecting the best mode of operation to continue in the MOT study, preliminary timeline analyses were made for each of the eight modes. Each timeline analysis covered a period of 9 days and included an example of each of the seven types of observations. The purpose of this preliminary analysis was to determine if significant differences existed between modes in utilization of available observation time. The example shown is for Mode IIIC and illustrates the method used. Estimates were made of time required for shuttle transfer and docking; pressurizing and depressurizing the cabin, servicing the optical auxiliary equipment, stabilizing the telescope, etc. Certain remote control capability was assumed.

The results of these analyses are not considered to be absolute, but rather are of value only in a relative sense. An actual observation program would probably utilize a given equipment setup as much as possible in order to minimize the number of trips to the telescope. For example, when the telescope is set up for use of f/30 equipment, experiments involving stellar high-dispersion spectra, planetary high-dispersion IR spectra, thermoelectric measurements, and planetary photographic work could all be accomplished by changing the orientation of the f/30 folding mirror.

Subsequent timeline analyses of this type will be aimed at determining the most efficient way of utilizing the telescope. They should also more accurately indicate the number and frequency of trips by man to the MOT for normal operations.

TYPICAL TIMELINE ANALYSIS

MODE III C



CONFIGURATION DESIGN & SUBSYSTEM INTEGRATION

CONFIGURATION DESIGN AND SUBSYSTEM INTEGRATION

The configuration design and subsystem study efforts are summarized under the five technical areas listed on the accompanying illustration.

The study was tailored to generate technical data required to conduct preliminary engineering and operational analyses.

It included defining a centerline configuration, establishing the feasibility of packaging an f/4 primary mirror telescope within acceptable payload requirements for the Saturn IB launch vehicle and evaluating alternate modes of operation and problem areas.

The last item, "Orbit Operational Performance" in the figure, refers to selection of operating orbital altitude and how altitude is related to the MORL and MOT configuration in terms of ballistic coefficients, control disturbance torques, and radiation protection.

CONFIGURATION DESIGN & SUBSYSTEM INTEGRATION

- MAJOR DESIGN FACTORS
- ORBITAL & LAUNCH CONFIGURATIONS
- SUBSYSTEM & DESIGN INTEGRATION
- WEIGHTS
- ORBIT OPERATIONAL PERFORMANCE

MAJOR DESIGN FACTORS

The design criteria items listed here are the major considerations taken into account in developing MOT conceptual configurations. The telescope optical geometry and the cabin for housing the experiment equipment and crew at the Cassegrainian focus are the dominating features governing the basic vehicle dimensions in orbit. The launch configuration is governed by the paylaod geometry that is acceptable atop Saturn IB. The launch loads and the thermal control required by the optical hardware are the most critical items governing structural design. Both the long operational life established for the MOT and the experiment versatility results in many requirements for setup and maintenance by man in orbit. These requirements call for unique design and installations due to man's limitations while working in zero gravity and in a spacesuit.

Each of the design factors listed was utilized somewhat in preparing orbital and launch configurations which defined the general arrangement of major systems and preliminary structural concepts. To establish conceptual configurations for eight modes of operation, a basic orbital design was developed that could be adapted to the various requirements by the addition or deletion of subsystems and external structure. This design was also utilized as a centerline for which preliminary weights, mass moments of inertia, and surface aress were defined for preliminary performance analysis. Outboard profile sketches were prepared showing how the centerline configuration accommodates the various modes of operation. The different design characteristics and interface problems with the MORL were examined for each mode and data was prepared in accordance with the criteria established for mode-of-operation evaluations.

MAJOR DESIGN FACTORS

- MOT MAJOR SYSTEM REQUIREMENTS
  OPTICAL SYSTEMS, EXPERIMENTS, & CREW SYSTEMS
- ORBITAL OPERATIONS
  RENDEZVOUS, DOCKING, MAINTENANCE & ORBIT KEEPING
- LAUNCH--SATURN IB BOOSTER
  DESIGN & PERFORMANCE--CONSTRAINTS & CHARACTERISTICS
- ORBITAL ENVIRONMENT
  TEMPERATURE, MICROMETEOROIDS, & RADIATION
- MOT PERFORMANCE
  VERSATILITY, SIMPLICITY, 3-YEAR LIFE, ETC.

ORBITAL CONFIGURATION

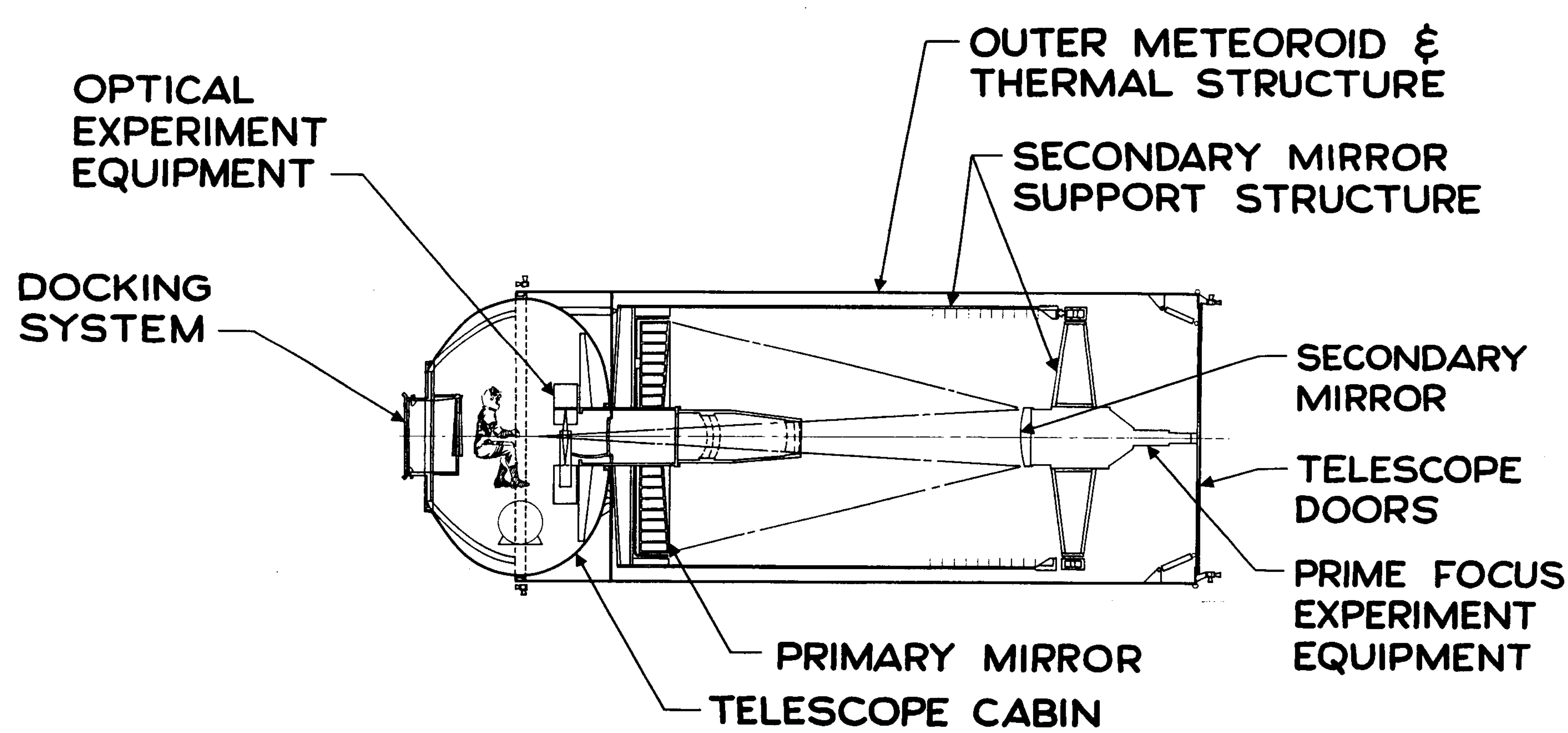
f/2 Primary Mirror Telescope

The design study, as originally proposed, was based on using a 120-inch f/2 primary mirror telescope configuration that was developed by the J. W. Fecker Division of the American Optical Company. This configuration was generated as part of a 120-inch orbital telescope feasibility study which was conducted for NASA. The MOT preliminary concept shown on the accompanying page reflects the basic telescope geometry of the Fecker concept with the exception of the pressure type cabin, supporting structure, and telescope doors that were added.

Subsequent Boeing studies have shown that an f/4 primary mirror telescope has an optical-geometry and mirror-surface tolerance range that appears more attainable in the MOT application. Once preliminary layouts showed that an f/4 primary system could be packaged in the Saturn IB launch vehicle, the f/4 system was adopted as the centerline telescope geometry for the MOT study. Except for an increase in length, the f/2 primary mirror system is quite similar to the f/4 centerline configuration. The general description of the configuration is therefore covered in more detail under f/4 orbital and launch configurations.

ORBITAL CONFIGURATION

f2 PRIMARY MIRROR TELESCOPE



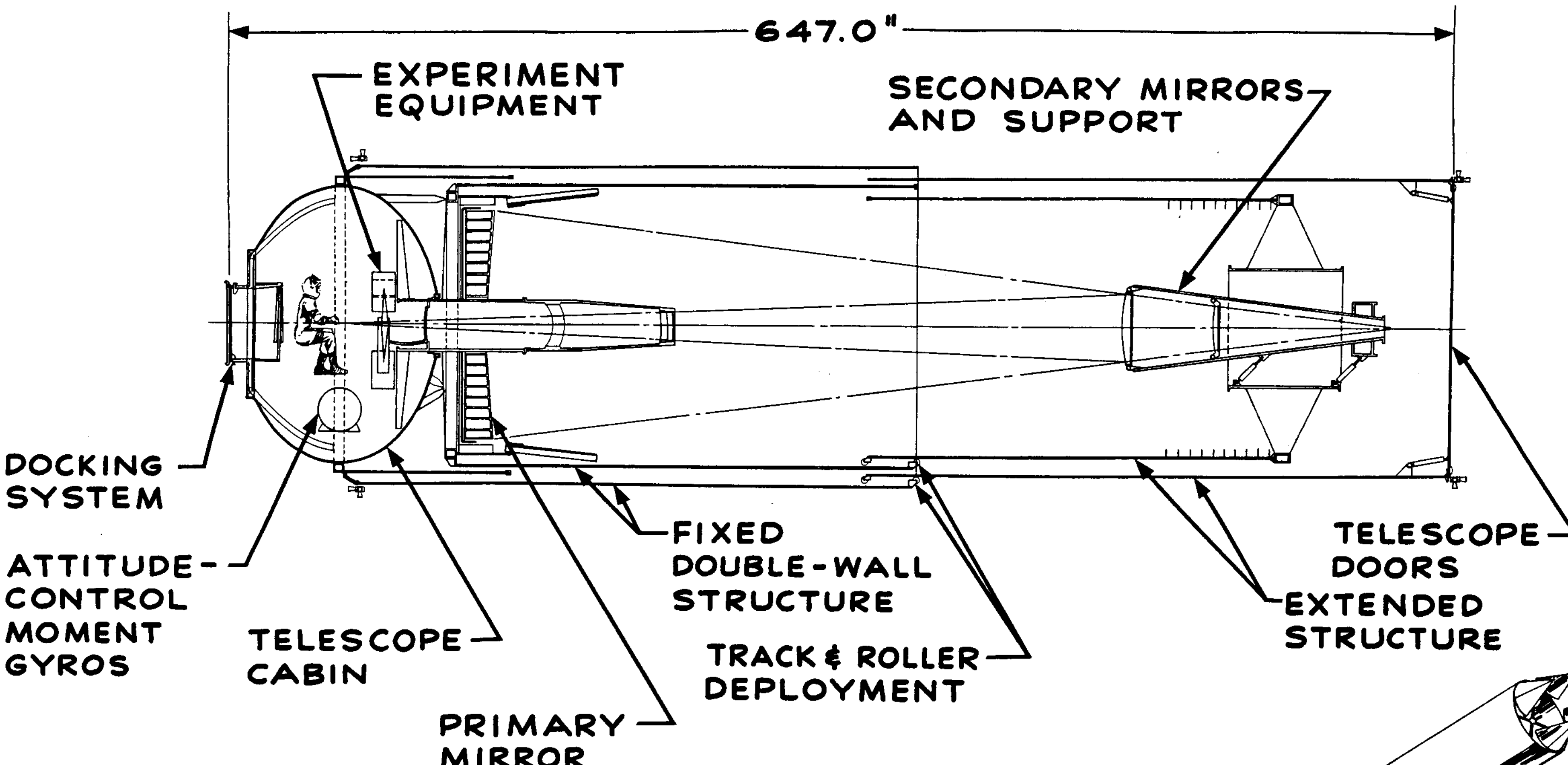
ORBITAL CONFIGURATION

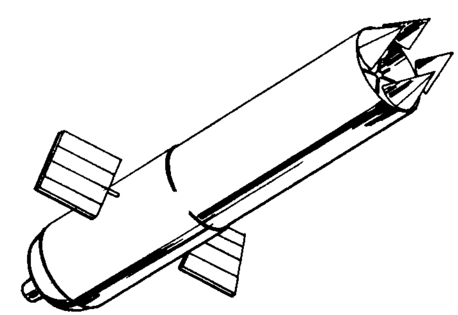
f/4 Primary Mirror (Telescoping Structure)

This orbital configuration is the centerline preliminary concept for a 120-inch f/4 primary mirror telescope using an extendable structural design to attain a smaller payload package for launch. Some of the design areas of major interest on the MOT are noted. The design has a double-wall tubular structure divided into a fixed and an extendable section. The fixed section is permanently attached to the primary mirror cell structure and the telescope cabin. The extendable structure supports the secondary mirrors and the telescope doors. The extendable structure is deployed by a track and roller design. There are three track and roller combinations, located at 120-degree intervals around the circumference, supporting the extendable cylindrical sections relative to the fixed sections. Automatic deployment is achieved by electric-motor-driven rollers.

Although the MOT is shown not coupled to the MORL, the basic telescope and cabin remain the same except the additional structure required for permanently attached modes of operation (Modes IA and IB). The basic cabin design is used for all modes of operation. It was retained for meteoroid and radiation protection and thermal balance in those modes of operation not requiring a shirtsleeve atmosphere for the crew. Cabin volume is approximately 630 cubic feet. The two secondary mirrors shown are for the Cassegrainian f/15 and f/30 focal ratios (the f/15 being nearest the primary mirror). Experiments requiring a smaller focal ratio or faster optical system would be conducted at the prime focus (f/4). The reduced scale sketch in the lower right corner of the figure depicts a dual solar panel concept for electrical power.

ORBITAL CONFIGURATION
f 4 PRIMARY MIRROR TELESCOPE (TELESCOPING STRUCTURE)





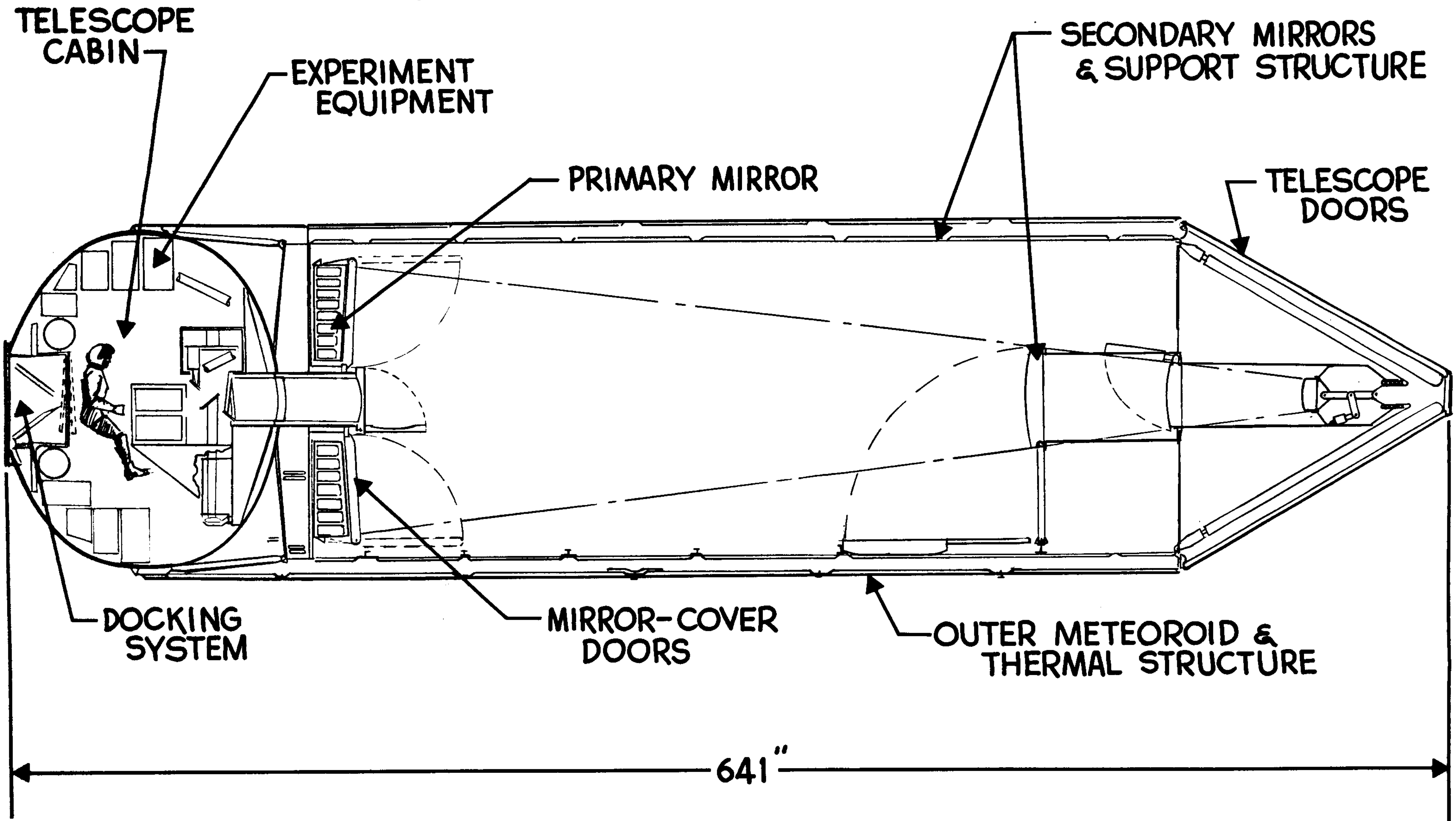
ORBITAL CONFIGURATION

Fixed Geometry Concept

Design studies included investigation of a 120-inch f/4 primary mirror telescope that has a fixed geometry in the launch configuration and does not require erection in orbit. The accompanying orbital configuration is a preliminary design of this concept. There are two changes in the telescope optical requirements for this design compared to the telescoping concept previously shown. They are the elimination of the experiment requirement at the prime focus and utilization of a variable Cassegrainian focus point within the cabin. The experiments that were previously schedules for the prime focus are conducted at the Cassegrainian f/8 focus in the cabin. The different designs for secondary mirror supports and telescope doors shown in this concept are the major design changes which permit the utilization of the volume in the nose cone of the launch configuration. These changes reduced the launch packaging height to within an acceptable payload profile for the Saturn IB. The pyramidal door design shown can have flexible-material panels between the six metal panels, forming a cylindrical sun shield for the secondary mirrors and support when the doors are open for observations.

ORBITAL CONFIGURATION

f4 PRIMARY MIRROR TELESCOPE



f/4 LAUNCH CONFIGURATION

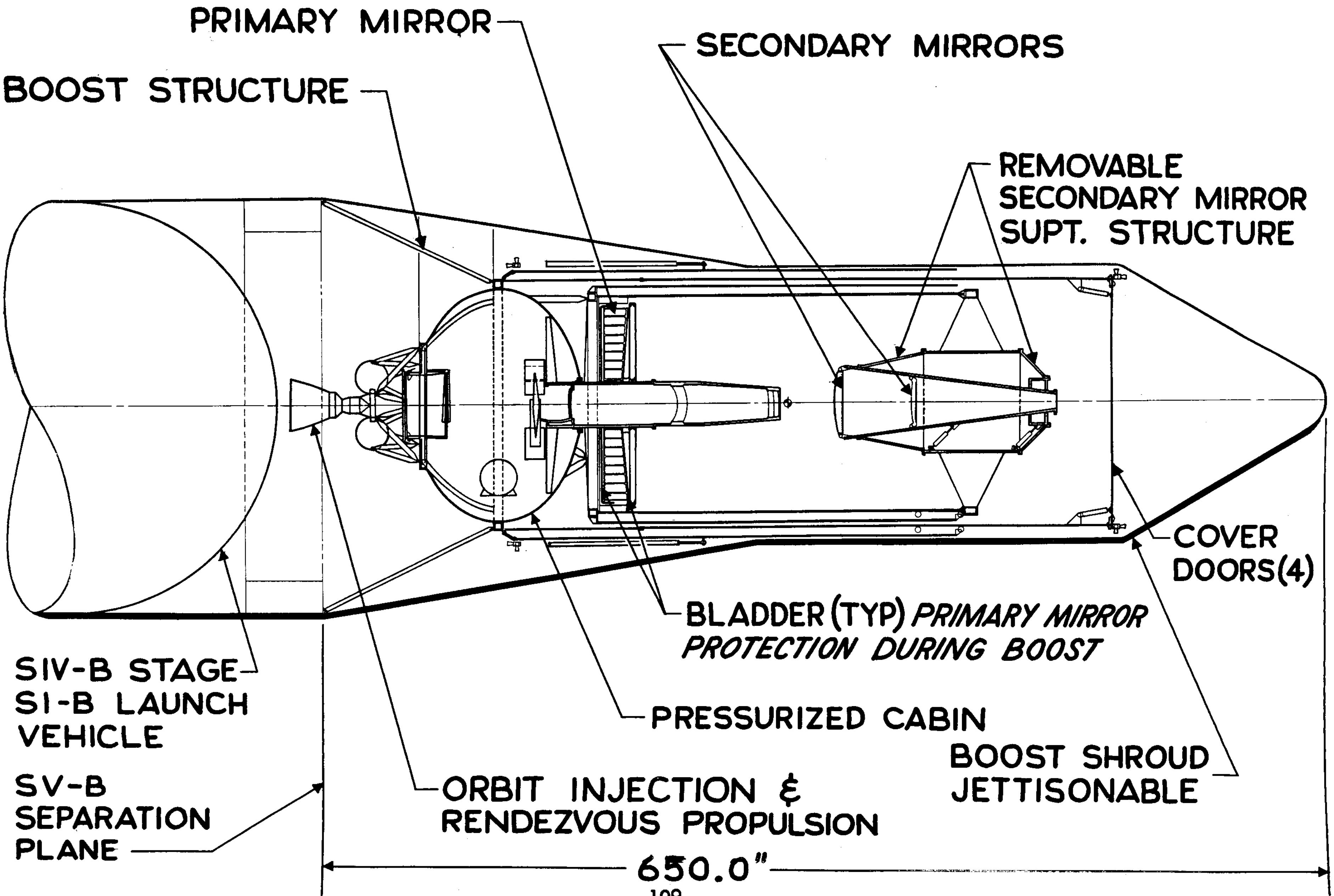
Telescoping Structure

The MOT launch configuration shown here depicts the general arrangement of major systems and basic structural requirements of the telescoping structural concept. The deployment method was defined in the description of the orbital configuration. The launch configuration shows the extendable section retracted which gives reasonable height for the Saturn IB payload package. The MOT is a nonintegral design with the boost shroud similar to the LEM vehicle mounting in the Apollo adapter. The outer boost shroud is jettisoned after Saturn IB first-stage burnout. By this technique, the payload to orbit is only penalized by approximately 12 percent of the boost shroud actual weight. The final decision on use of this design approach depends on a detailed engineering study to determine if the boost shroud can be efficiently used as the outer shell of the telescope in orbit. At present it appears more efficient to jettison the boost shroud and use the weight to orbit for selective structural design, selective insulation, and to provide a MOT exterior surface coating protected from launch environment.

The MOT propulsion system shown is the LEM ascent system with modified tankage and structural support. This system is used after separation from the Saturn IV booster for a hohmann transfer and orbit injection associated with MOT/MORL rendezvous.

In several areas the telescope requires special designs or support systems to accommodate boost load criteria. Examples of these design areas noted on the launch configuration drawing are: primary mirror uncoupled from the support structure and floated on a penumatic bladder suspension system to provide uniform loading during boost; and secondary mirror cell structure rigidized by additional structure that is removed by the crew after the telescope is in orbit.

f4 LAUNCH CONFIGURATION
TELESCOPING STRUCTURE



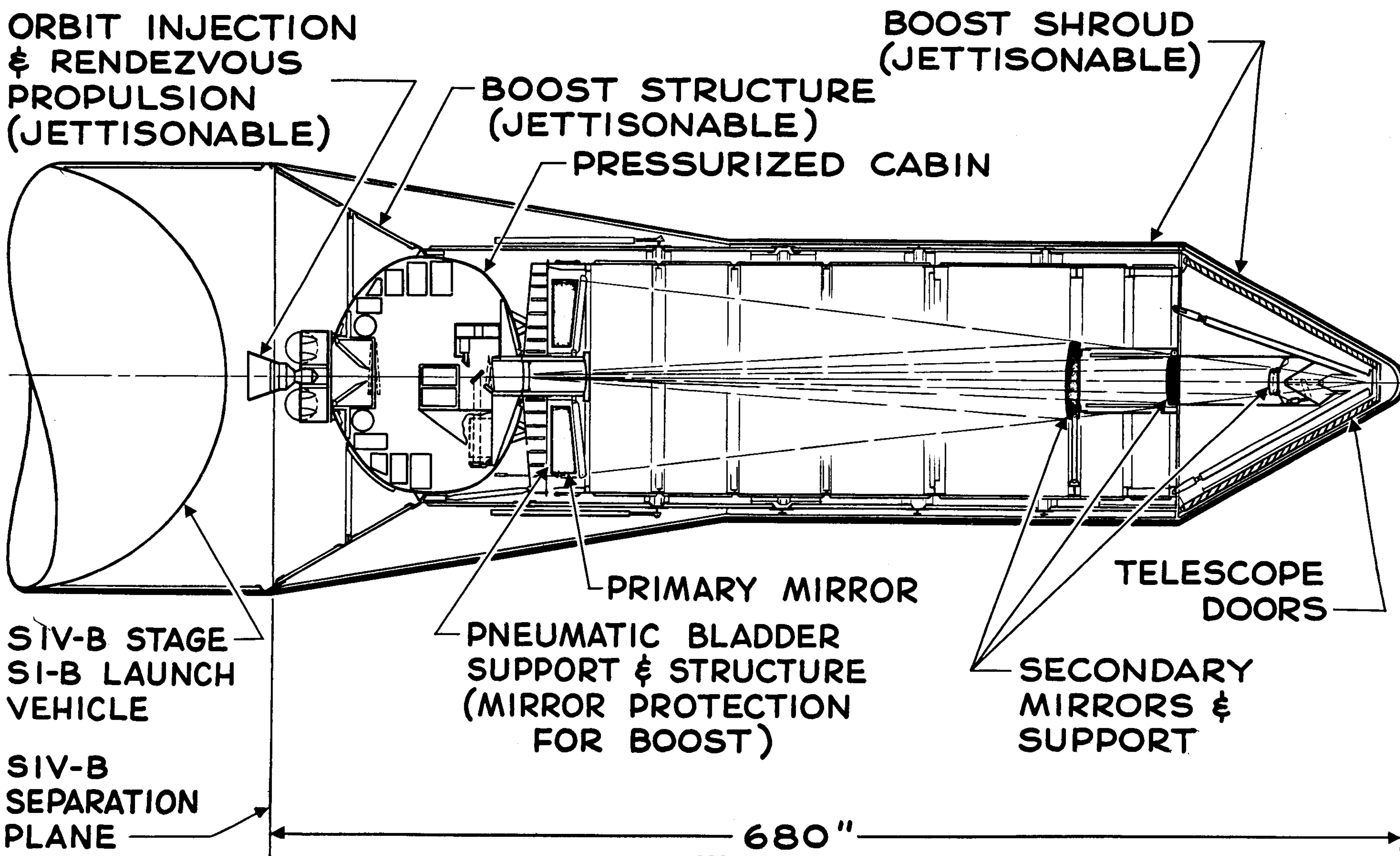
f/4 LAUNCH CONFIGURATION

Fixed Geometry

The subtitle Fixed Geometry refers to a telescope design in which the secondary mirror and supporting structure remains fixed from launch to orbit. After the original f/4 centerline was generated, a growing concern arose as to the practicality of having a secondary mirror cell that had to be extended and rigidized inorbit. Most of this concern was related to the additional penalties that would be imposed on the adjustment and control of the secondary mirror relative to the primary mirror and the general complexity of the deployment system. Design studies were therefore initiated to develop the concept shown on the accompanying page. In general, the basic system and structural philosophy employed previously were applied to the cabin and secondary mirror tubular support structure. The telescope doors were changed to a pyramidal design to obtain the minimum launch heights. Although this concept increases the launch profile height by 30 inches, it is believed to be within presently acceptable limits.

As the design was created several months after the original centerline, other new structure design features were incorporated that will form a part of the structural design trade studies to be conducted during the next phase of study. A few of these features are: single axis freedom of the secondary mirror cell which is supported on flexure bars; primary mirror supported at its circumference by tangent flexure bars; and enlarged cabin and updated experimental instrument arrangement. It should be noted that if the pyramidal door design was applied to the telescoping structure concept, its launch height could be reduced about 100 inches.

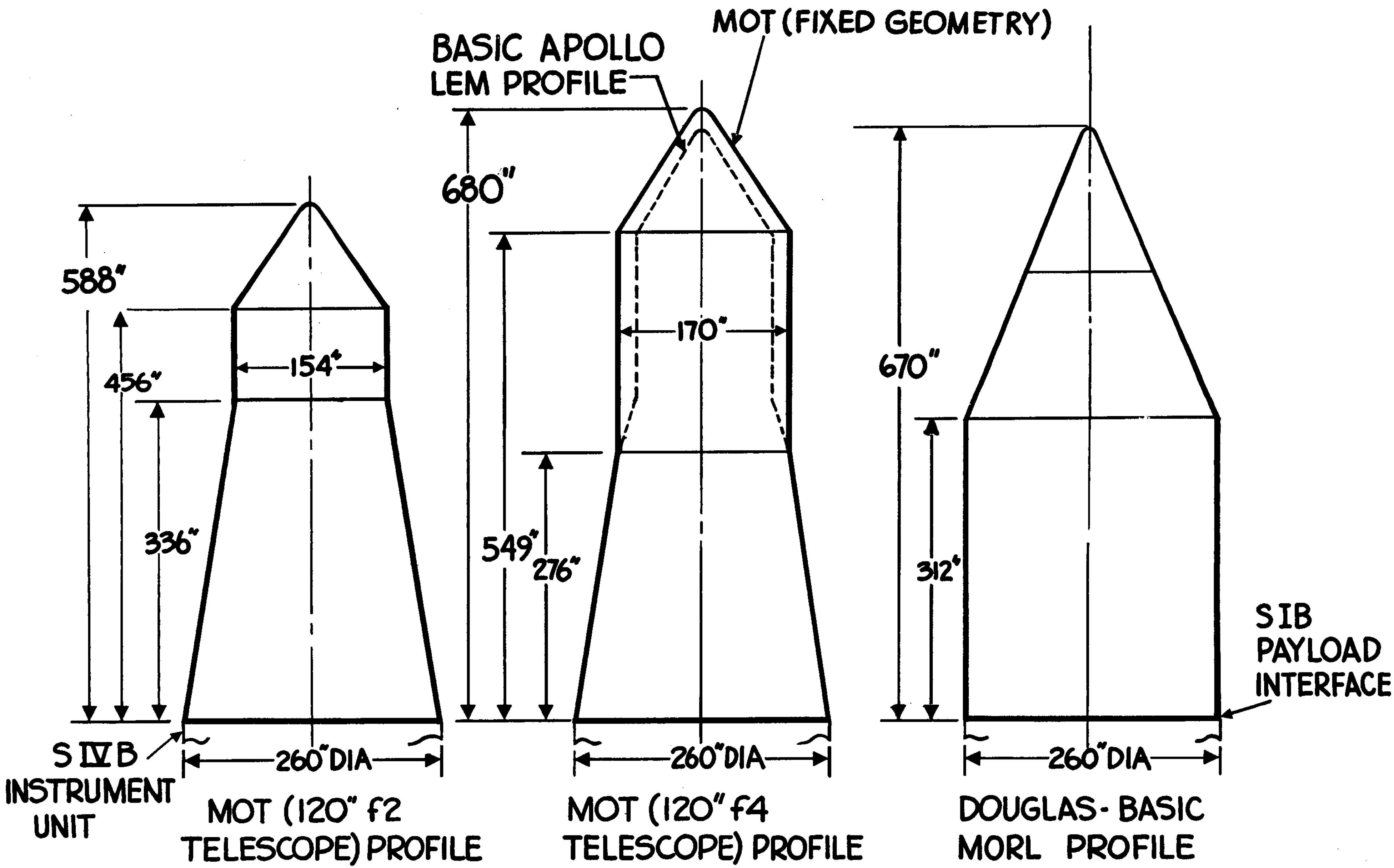
f4 LAUNCH CONFIGURATION
(FIXED GEOMETRY)



LAUNCH PROFILE COMPARISON

One of the MOT study proposal requests was to select a launch vehicle to establish payload compatibility. The Saturn IB was selected as the launch vehicle best suited for placing the MOT in orbit. Payload to orbit, launch payload geometry, and Launch environment defined for this booster were considered closest to the MOT requirements. Originally the study was based on a MOT with a f/2 primary mirror telescope. This telescope concept was determined to fall well within the growth performance forecast for the Saturn IB and the launch configuration profile established for the Apollo program. During the early phase of study the centerline telescope design was changed from an f/2 to an f/4 primary mirror system. New branch configuration preliminary layouts were made to establish the compatibility of this larger telescope with the Saturn IB. In order to show the MOT f/4 launch configuration requirements, the accompanying chart compares launch profiles of the original f/2 design, the f/4 fixed geometry design, and the proposed Douglas MORL. The fixed geometry design is approximately 30 inches higher than the telescoping design. The Apollo profile is superimposed on the MOT fixed structure concept to show the relative increase in launch profile that may be required for the MOT. The increases in the launch geometry, the estimated launch weight, and the mass distribution are considered within the compatibility range of the projected 1975 Saturn IB launch vehicle.

LAUNCH PROFILE COMPARISON



SUBSYSTEM DESIGN AND INTEGRATION

The MOT subsystems are divided into two categories for this phase of study to identify those sensitive to the various modes of operation. Those systems listed under Telescope Optical Systems are defined quite independently of the mode of operation and make up the basic center-line configuration. The systems listed under Supporting Subsystems are, in some cases, directly affected by the mode of operation such as Attitude and Orbit Control and MORL Interface Structure, while others fall into a trade study area. Electrical, Orbit Control, and Atmosphere Supply systems are quite sensitive, not only to mode of operation but to the philosophy of the MOT's dependency on the MORL subsystems. MORL Interface Structures listed under supporting subsystems refers to the docking system and the rigid or gimbal attachment for Mode I. The tether cable and the floating socket design for Mode II would also fall into this category.

SUBSYSTEM DESIGN & INTEGRATION

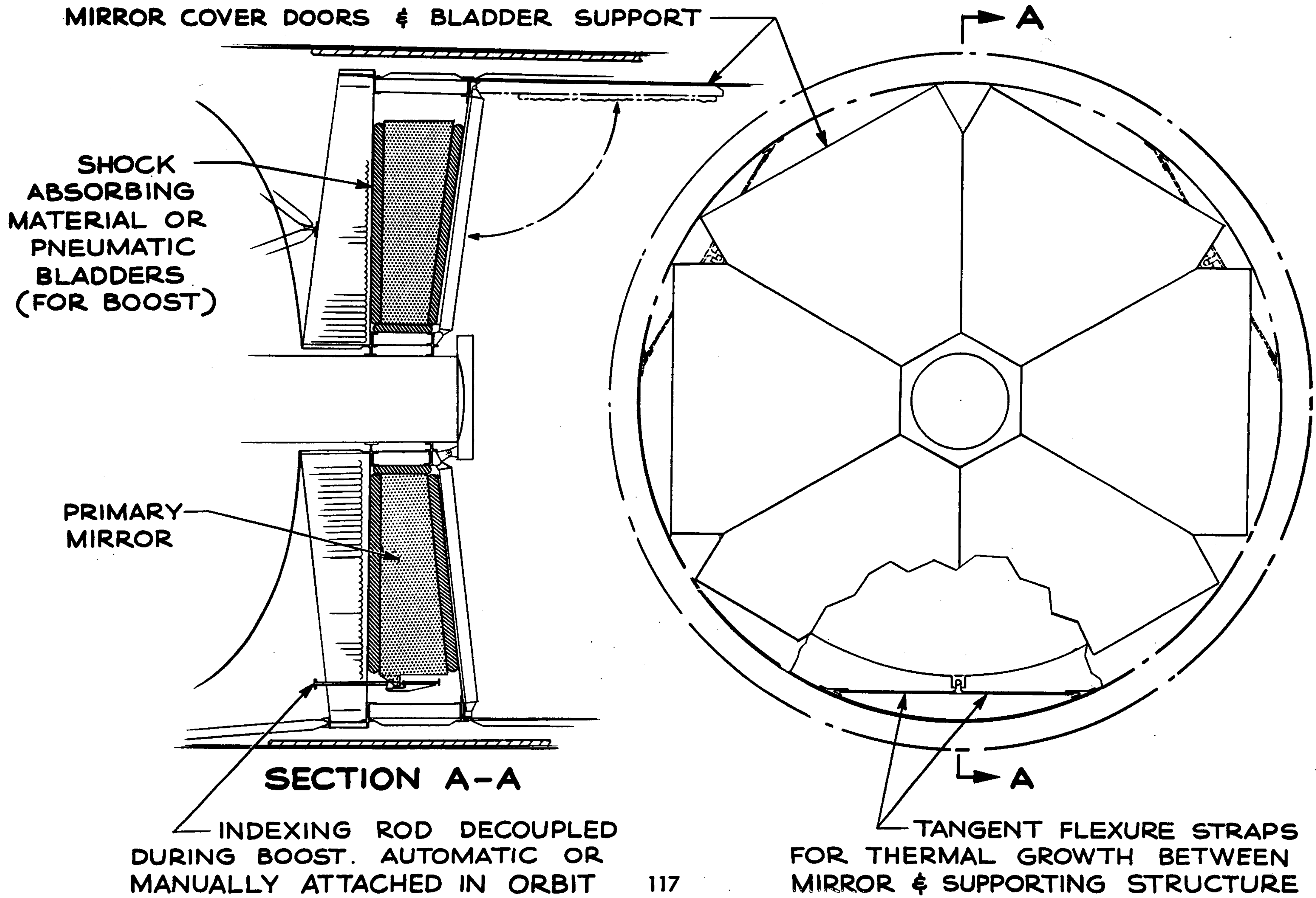
- TELESCOPE OPTICAL SYSTEMS
  - PRIMARY & SECONDARY MIRRORS
  - EXPERIMENT EQUIPMENT--SPECTROGRAPH, CAMERAS, ETC.
  - STRUCTURES--MIRROR SUPPORTS, CABIN, ETC.
- SUPPORTING SUBSYSTEMS
  - ATTITUDE & ORBIT CONTROL
  - ELECTRICAL
  - ENVIRONMENTAL & LIFE SUPPORT
  - COMMUNICATIONS & DATA MANAGEMENT
  - MORL INTERFACE STRUCTURES

PRIMARY MIRROR INSTALLATION

The primary mirror installation is a major design problem area. The mirror is very sensitive to thermal gradients and, until more definite material-yield criteria for mirrors can be established, design precautions must be taken to isolate the mirror from boost loads and vibrations. Here we see two installation design features that are being evaluated. The first is the pneumatic bladder suspension which is used to attain uniform loading on both mirror surfaces. Bladders are used on both sides because of the negative g's that occur during boost engine cut-off. The concept requires the physical structural attachment of the mirror to be uncoupled during boost. This is accomplished by disengaging the three index rods and retracting them to allow for the necessary float of the mirror. After the MOT is in orbit, the rods must be re-engaged, either automatically or manually. Although pneumatic bladders are shown, the investigation will include other shock-absorbing materials. The pneumatic pressure in the bladders should be controlled to a small value above atmospheric pressure during ascent to orbit to minimize the load on both the mirror and supporting structure. The mirror doors, to which the bladder segments are attached, are used to protect the delicate mirror surface from foreign material.

The second feature illustrated is the three-point tangent flexure strap mounting between the outer rim of the mirror and the primary structure. This permits differential expansion between the mirror and the primary structure without inducing large loads into the mirror. The three-point mounting also permits the plane of the attachment points to tilt without inducing stresses into the mirror.

PRIMARY MIRROR INSTALLATION

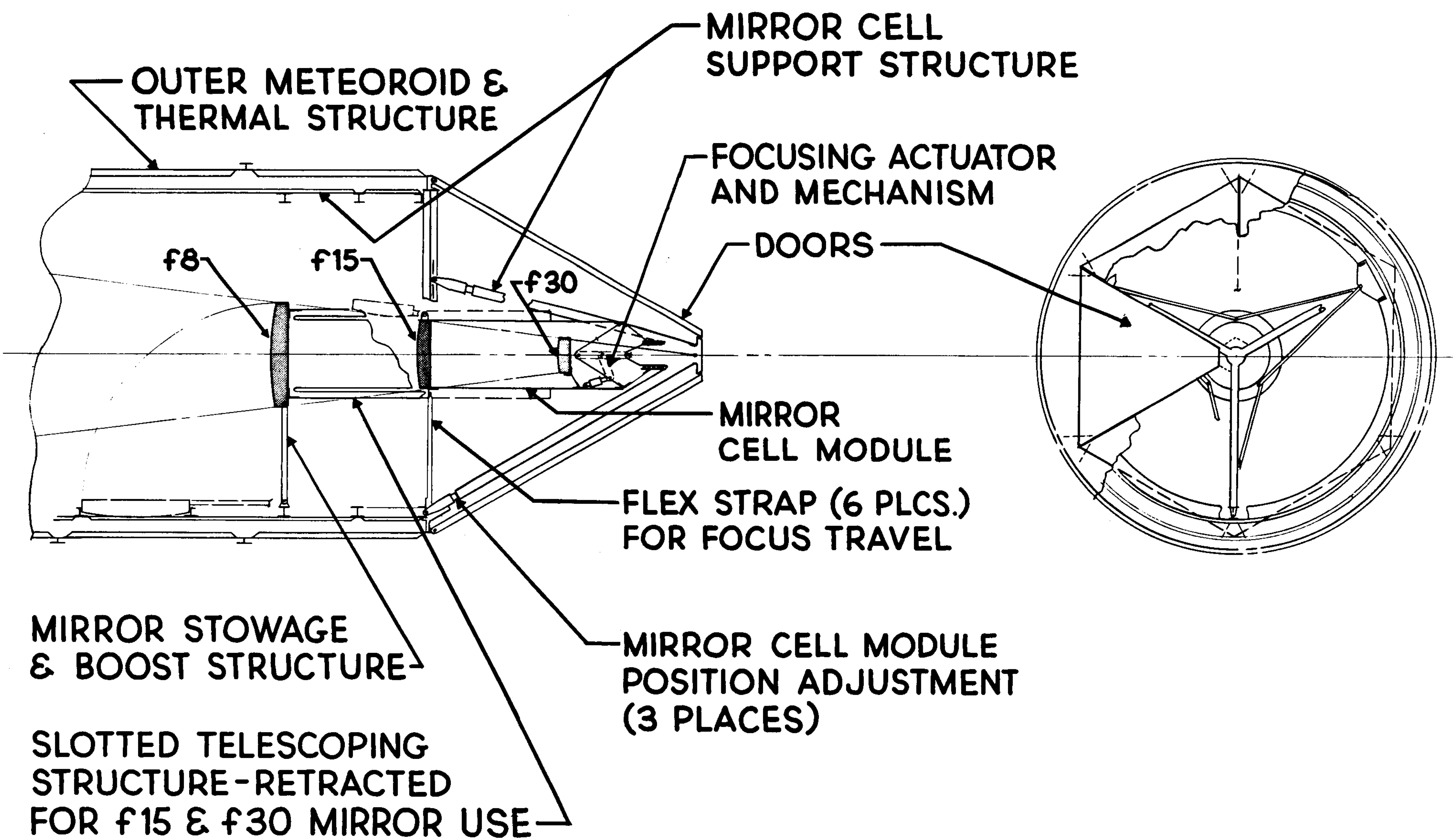


SECONDARY MIRROR INSTALLATION

The telescope secondary mirrors have several installation problems. This figure depicts a preliminary conceptual design which is used primarily to present some of the problem areas. Some of the alignment problems associated with controlling the position of the secondary mirrors relative to the primary mirror are covered in the section on optical geometry control. These involve both the primary support structure and the focus control. This concept assumes a servo control only for one axis of freedom which is positioning for focus. The secondary mirror module is supported by a flexure strap design at the midpoint near its center of mass and by a sliding support in the apex of the truss support. The complete mirror module is moved for focus control. This principle is being compared to independent control for each of the three mirrors. Adjustment devices are provided in the three truss support bars for alignment of the secondary mirror module. These may be manual or automatic depending on how often alignment is needed and whether it can be done manually. The f/8 and the f/15 mirror must be removed or hinged to be moved out of the way when the f/30 mirror is used.

The six telescope doors are shown in this sketch and form a pyramid over the truss structure when closed. There are fabric panels between each door which form a cylindrical light shield when the doors are open. Two other design problems are maintenance and the minimizing of support structure and mirror sizes to obtain an acceptable obscuration ratio. This refers to the percentage of light blocked from the primary mirror by the secondary mirror and structure.

SECONDARY MIRROR INSTALLATION



CABIN ARRANGEMENT

The telescope cabin arrangement is dictated largely by the optical requirements of the three different focal ratios and the requirements of the auxiliary equipment used with each one. Offset guidance requirements for f/8 and f/15 equipment further complicate the cabin arrangement problem.

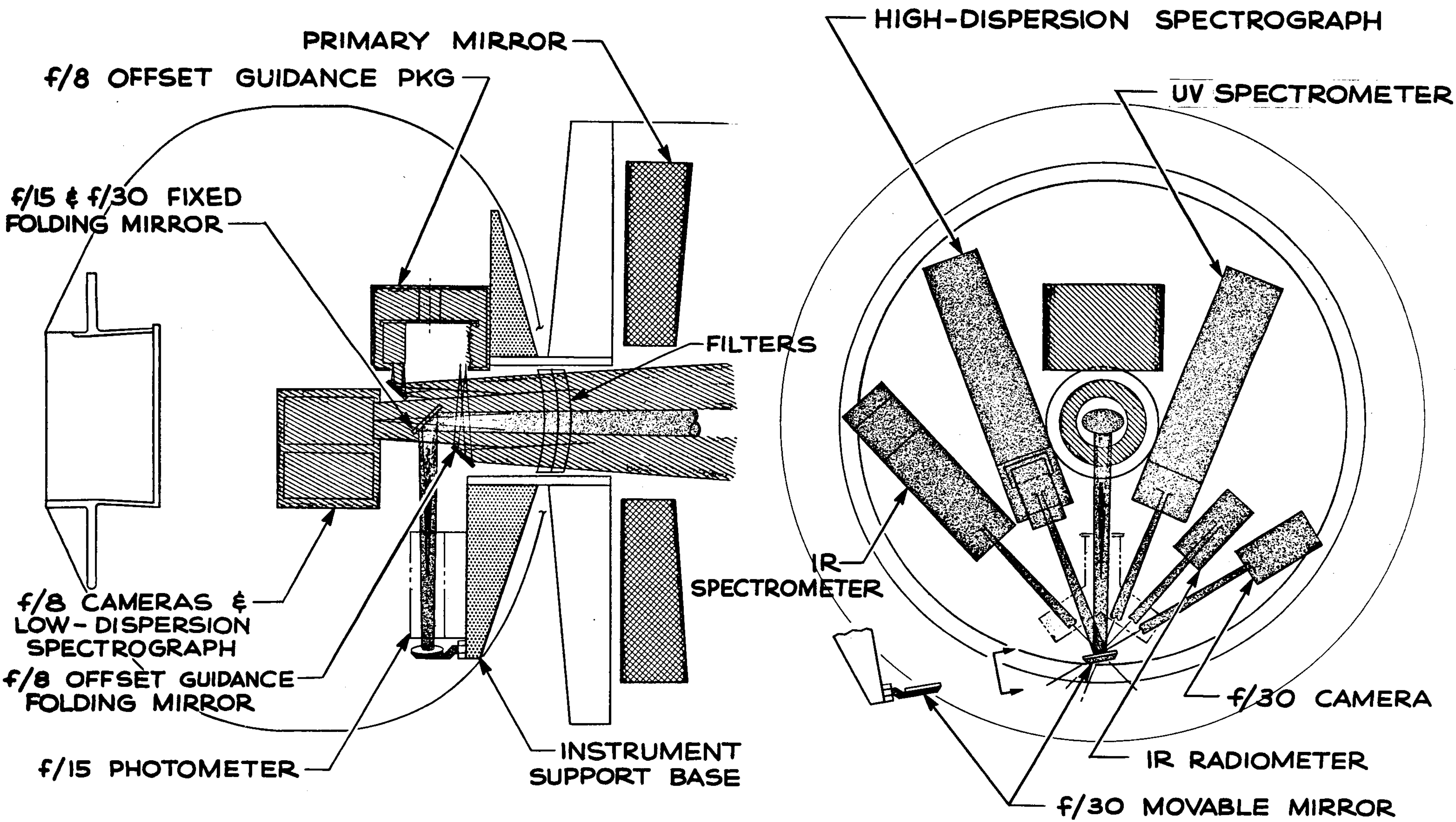
The arrangement shown is one approach to this problem and utilizes a different focal plane for each of the focal lengths. A fixed folding mirror and a movable one make it possible to direct the f/30 beam to each of the appropriate pieces of equipment. The movable mirror could be mechanized for remote control from the MORL.

When the f/8 equipment is used the f/30 fixed folding mirror is removed. The large format requirement for f/8 photography in conjunction with the offset guidance requirement makes folding the f/8 beam to different pieces of recording equipment quite difficult. The present cabin arrangement requires that the f/8 camera be removed when the low dispersion spectra equipment is to be installed. The f/15 camera and the photoelectric photometer also share the same position during observations. However, subsequent work in this area will examine alternate concepts for arranging and operating the optical auxiliary equipment.

Detailed consideration has not yet been given to subsystem packaging and arrangement within the cabin, but this equipment will be as isolated as possible from the optical elements.

The structure which supports the experiment equipment relative to the primary mirror must be rigid, thermally stabilized, and not subject to misalignment from distortion during a given observation.

CABIN ARRANGEMENT



ELECTRICAL POWER REQUIREMENTS

The defined MOT electrical power requirements result from a preliminary assessment of the various equipment that could be identified for a centerline concept representing Mode IIC. The electrical loads shown are for operation when the MOT is uncoupled from the MORL to perform astronomical observations. The guidance and control system requires approximately 67 percent of the total. The major equipment offenders of this system are the pitch and yaw control moment gyros (47 watts each), the star trackers (70 watts), and the fine error sensor (50 watts). The peak power for the control systems is based on not accelerating all the control moment gyros to operating speed simultaneously. In the optical equipment subsystems the UV spectrometer, IR spectrometer, and the IR radiometer each require approximately 50 watts but in this case only one instrument is used at a time. The high peak load for communications is associated with a docking maneuver when 100 watts are assumed for visual aid plus 35 watts for a tracking beacon. Environmental control requirements are the least defined and the electrical power is a best estimate at this time. The estimate for ECS increases to 200 watts when the crew is in the cabin, although this load occurs when other systems can be shut down. The preferred electrical power supply system operational and design characteristics for the MOT application are: a system that is independent of vehicle inertial attitude; operational characteristics that will not disturb the telescope during observations; and low maintenance and refurbishing requirements for a 3- to 5-year operating life.

ELECTRICAL POWER REQUIREMENTS

SYSTEM	LOAD (WATTS)	
	AVERAGE	PEAK
GUIDANCE & CONTROL	470	540
COMMUNICATIONS	30	150
OPTICAL EXPERIMENTS	50	50
ENVIRONMENTAL CONTROL		
TELESCOPE	50	50
CABIN – UNMANNED	100	100
SUB-TOTAL	700	890
ASSUM'G SOLAR CELL OR BATTERY SUPPLY		
PANEL ARTICULATION	20	50
BATTERY CHARGING	720	720
REGULAT'N & DISTRIBUT'N LOSSES	290	320
GROSS SOLAR PANEL REQM'TS	1730	1930

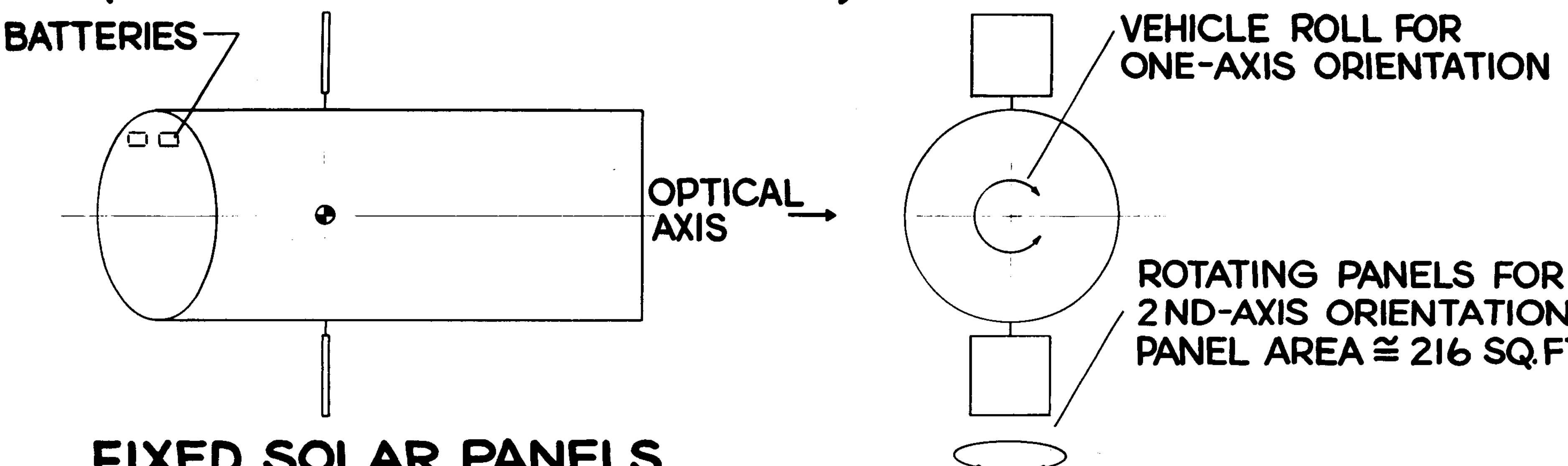
ELECTRICAL SUPPLY SYSTEM

The electrical power supply is considered a secondary problem area in establishing the feasibility of, or selecting the best configuration design for, the MOT. Industry has established that the solar cell and battery system is a reasonable choice for long-term (3- to 5-years) orbital space systems based on present state of the art and replacement plans. The centerline configuration has, therefore, used this system for study purposes. There are some MOT attitude stability and inertial orientation requirements that may lead to considering other power supply systems in future studies. Systems such as the RCA thermionic system using PU-238, which is nearly a static device and is independent of inertial attitude and orbit position, may be good prospects for large telescope applications.

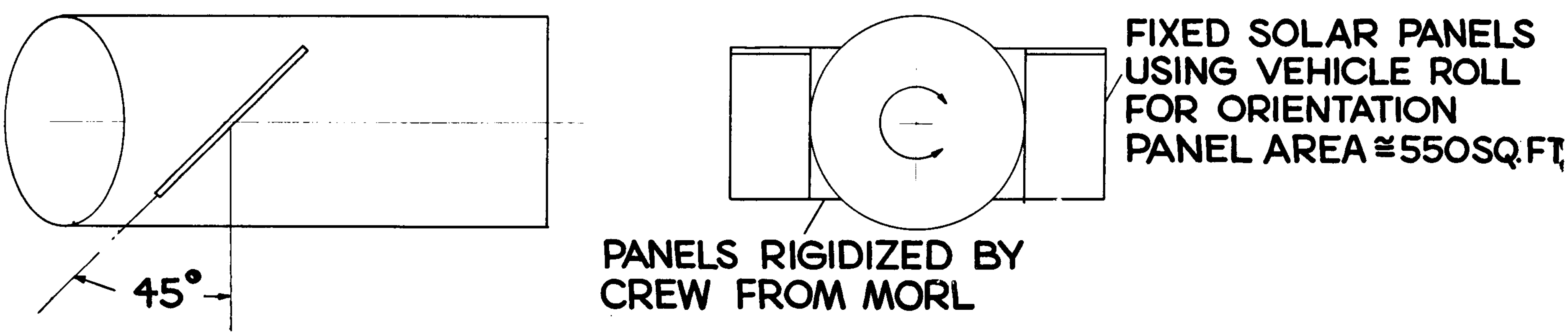
The conventional articulated solar panel design shown may cause undesirable servoelastic coupling problems in trying to hold 0.01 are second telescope control accuracy. If there is a servoelastic problem, the fixed structure panel installation may be used. It should be noted that a fixed solar panel design more than doubles the solar cells required even when the telescope inertial attitude is constrained to half that attainable with articulated panels. In addition, telescope off-axis fine-guidance sensors and/or thermal balance requirements may limit the permissible role of the MOT vehicle about the optical axis. This would impose a penalty that would double the solar panel area for both the articulated and the fixed panel concepts shown.

ELECTRICAL SUPPLY SYSTEM

ARTICULATED SOLAR PANELS
(GOOD FOR ALL INERTIAL ATTITUDES)



FIXED SOLAR PANELS
(LIMITED INERTIAL ATTITUDES)



GROSS SOLAR PANEL REQ'MTS 1730 WATTS

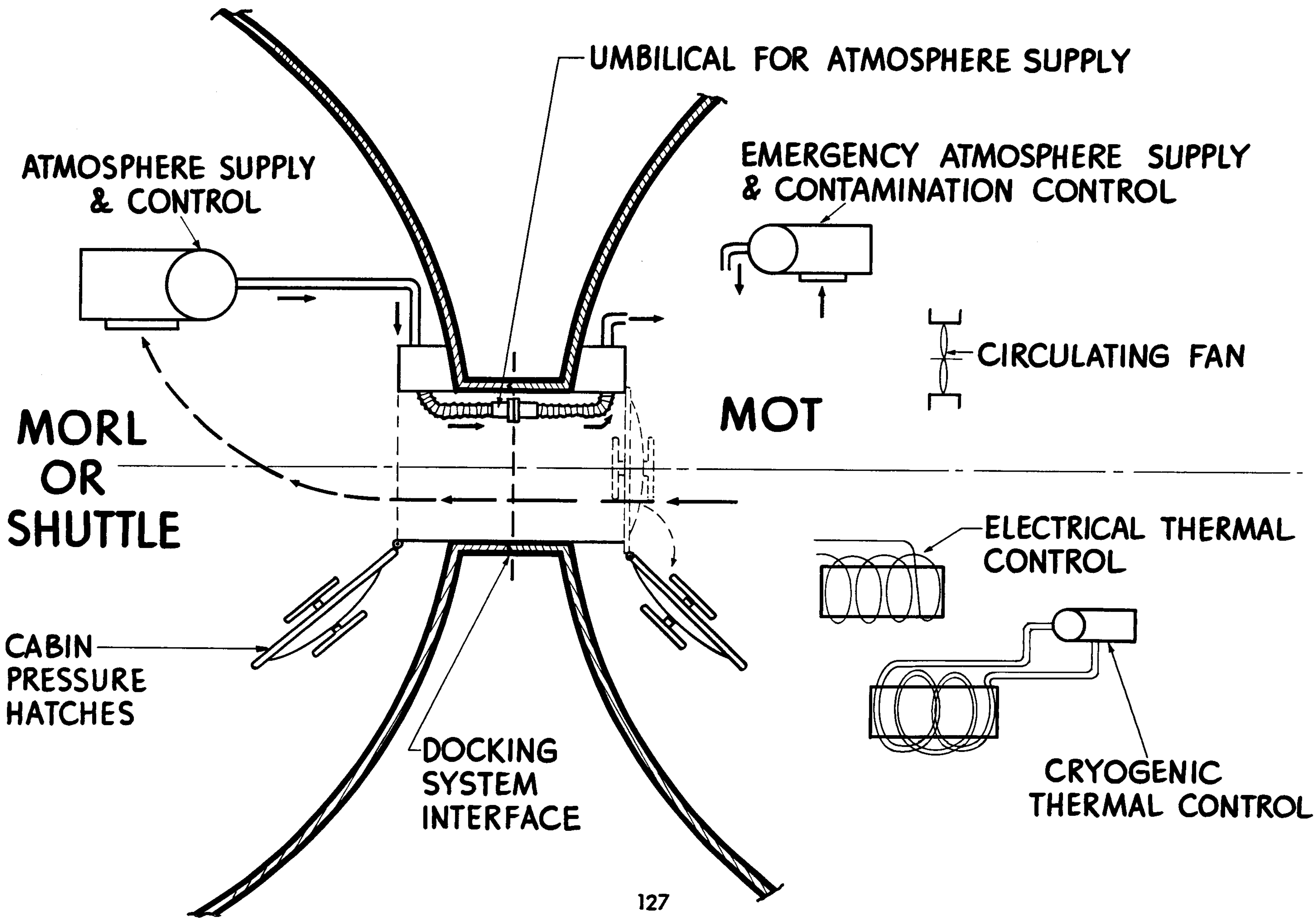
ENVIRONMENTAL CONTROL SYSTEMS

Environmental control includes both the atmosphere required for the crew and the active thermal control required in the MOT for various equipment or structural hardware. This schematic depicts the study centerline system for Modes IIC or IIIC. Here, the only time atmosphere required is in the MOT cabin is when the MOT is docked to the MORL (Mode IIC) or when the shuttle is docked to the MOT (Mode IIIC). Therefore, the docked condition is shown and demonstrates how the atmosphere would be supplied the MOT cabin from the MORL ECS system. This concept was chosen for the centerline because it represents the simplest approach, requiring a minimum of systems and components. By installing a small independent emergency system in the MOT, the reliability is no less than the basic MORL or shuttle atmosphere control system. The concept also limits the logistics resupply of atmosphere to the MORL rather than to both vehicles. The type of atmosphere used in the MOT becomes that of MORL or a shuttle.

An independent atmosphere supply and control system was also sized for MOT. This is a basic requirement for Mode IIIB. The preliminary study for an independent system showed that the amount of gas required for cabin pressurizatione once a day was so large that a pumpdown recovery system should be used. Best estimates indicate this problem severity will increase as the study progresses. As the experiment equipment is defined in more detail the cabin volume requirements increase.

Thermal control requirements for various equipment and structures on the MOT are still undefined. This depends considerably on the overall thermal balance problem. Structures are included as possible requiring active thermal control due to the extremely small distortions allowable in the optical systems. Preliminary studies indicate a possible requirement for heating and cooling.

ENVIRONMENTAL CONTROL SYSTEMS

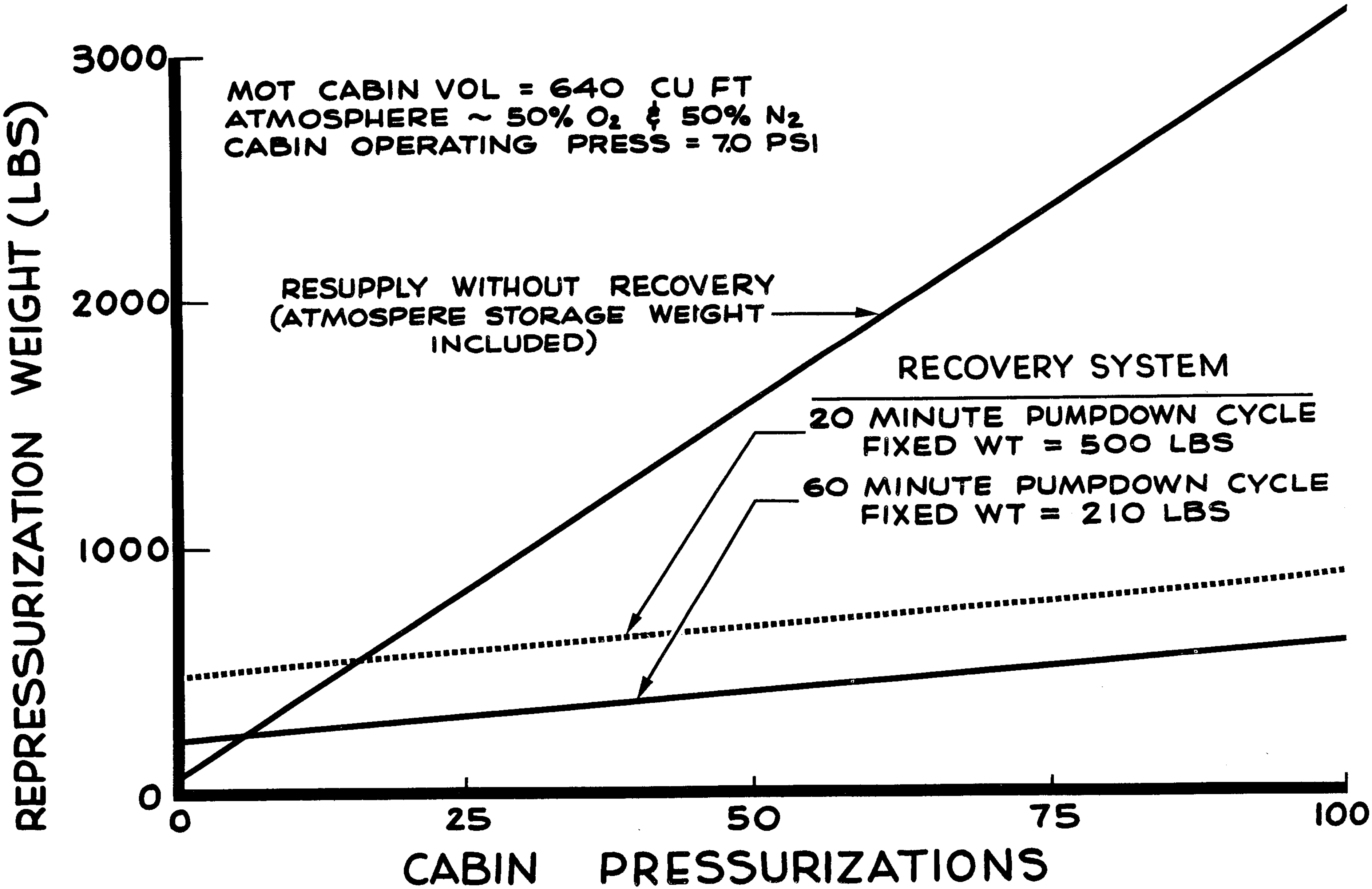


ATMOSPHERE SUPPLY STUDY

The cabin-pressurizing atmosphere can be recovered by pumpdown to an accumulator or be expended after each depressurization. This figure shows the weight trade between pumpdown equipment and resupply weight for increasing cycles of MOT repressurization. The repressurization weights without recovery are the amount of oxygen and nitrogen required plus the weight associated with the MORL subcritical storage tanks and 50 pounds for the transfer tank system. For the attached and docking modes, 50 pounds may be subtracted from the weights indicated. The recovery system weights are based on using a three-stage compressor with cooling between stages. The compartment is evacuated to 0.7 psia and the atmosphere is compressed to 200 psia. The weights for the recovery system include the compressor, added cooling circuit equipment, makeup atmosphere, added radiator, gas accumulator and the added silver-cadmium batteries required to supply the pumping power.

For attached and docking modes, a recovery system using the MORL Hangar/Test Area pumpdown system and 105 psia storage tank has been considered for pressurization while coupled. However, use of this system would require a pumpdown time of about two hours.

ATMOSPHERE SUPPLY STUDY



COMMUNICATIONS AND DATA HANDLING

The communications and data handling subsystem for MOT contains the elements necessary to perform the following functions:

- Receive and decode necessary commands, remotely control and operate the MOT
- Augment ground radar tracking for station-keeping purposes
- Acquire data and imagery needed for:
  - Monitor of equipment and vehicle status
  - Satisfactory completion of experiments
- Format and/or process acquired data for presentation to a using or storage device
- Transmit and receive processed data
- Display processed data to the astronauts
- Maintain continual voice contact between MORL and the astronauts at work in MOT

COMMUNICATIONS & DATA HANDLING

FUNCTION	REQUIREMENT	
	MORL	MOT
COMMAND	CONTROL PANEL COMMAND ENCODER COMMAND TRANSMITTER	COMMAND RECEIVER COMMAND DECODER
TRACKING		BEACON ANTENNA
DATA ACQUISITION SUBSYSTEM MONITORING EXPERIMENTS		TRANSDUCERS (FOR MONITOR & EXPERIMENT DATA) CAMERAS (FILM & TV)
DATA PROCESSING	TELEMETRY DECOMMUTATOR FILM PROCESSING FILM SCANNER DATA STORAGE	TELEMETRY ENCODING AND FORMATTING
DATA RETRIEVAL	TELEMETRY RECEIVER ANTENNA PHYSICAL TRANSFER TO EARTH 1	TELEMETRY TRANSMITTER PHYSICAL TRANSFER TO MORL ANTENNA 2
DISPLAY	TV IMAGERY CRITICAL FUNCTION MONITOR SELECTED EXPERIMENT DATA DISPLAY	
VOICE COMMUNICATION	TRANSCEIVER ANTENNA	TRANSCEIVER ANTENNA

1 FILM VIA SHUTTLE OR DATA CAPSULE

2 MAN'S ROLL IN RETRIEVING FILM FROM MOT

MOT COMMUNICATIONS

Part numbers in the diagram demonstrate off-the-shelf availability of components and do not represent a final design. Final design is influenced by the rf transmission range, the measurement list, command requirements, etc., which are subject to change. Assumptions pertinent to the design are that maximum range is one mile, power is more critical than weight, and that antennas can be placed so nulls in the radiation pattern that are greater than 20 db down are avoided.

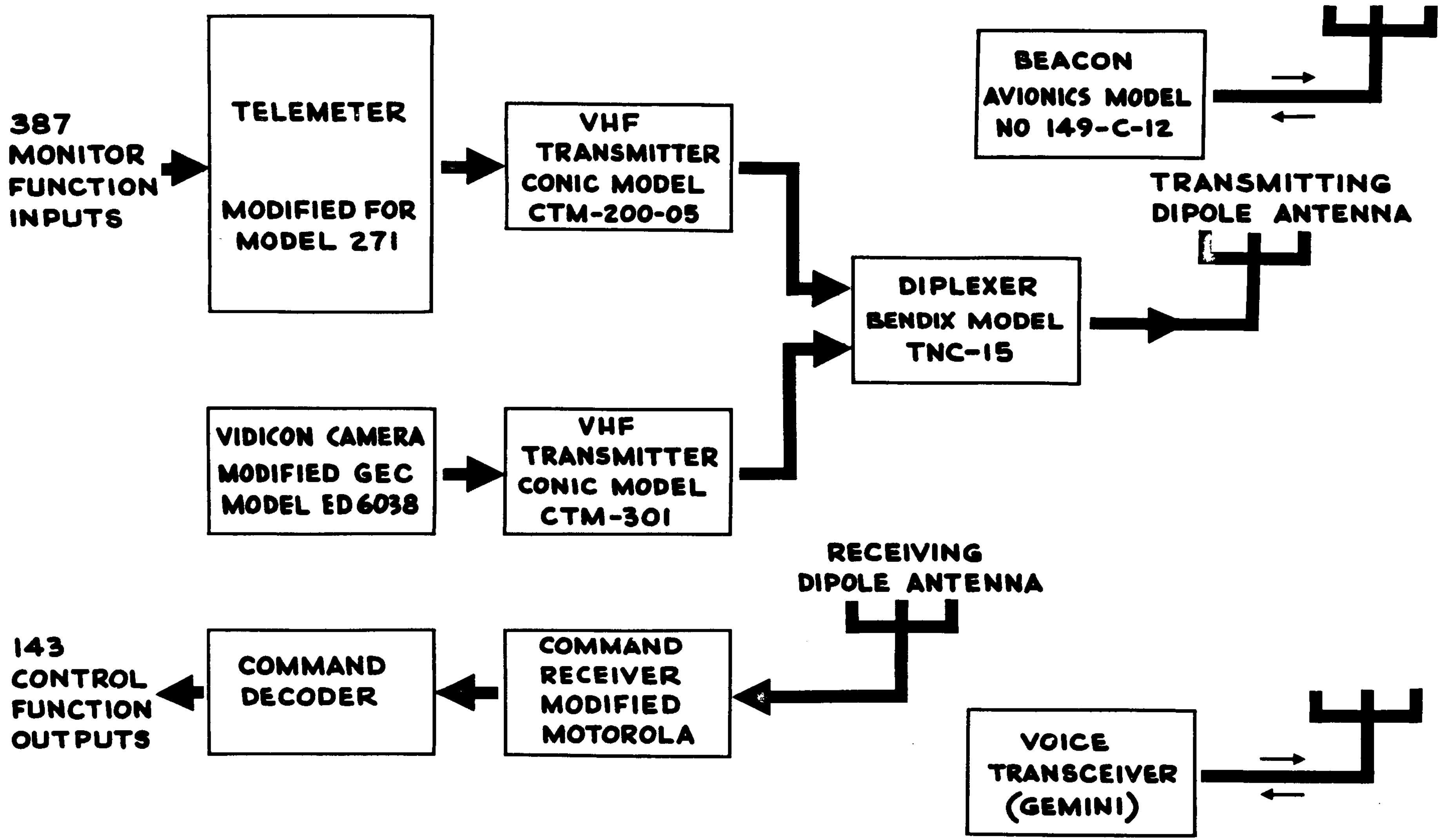
The MOT communications subsystem consists of a radar beacon, and command, telemeter, TV, and voice subsystems.

The beacon transponder and its antenna complement ground-based pulse radars (FPS-16 or FPQ-6) to enhance ground tracking for ephemeris determination.

The command subsystem includes an antenna, a receiver, and a command decoder. The command receiver, operating at approximately 400 mc, discriminates the frequency-modulated rf signal from MORL. The decoder identifies the commands and addresses them to the proper subsystem or equipment.

PCM telemetry data is derived from approximately 300 sources. Vehicle and equipment status data are sampled at rates up to 2 samples per second and experiment data up to 1200 samples per second. Continuous voice communication between MORL and MOT isprovided by the voice transponder. Either Gemini or Apollo transponders will be used.

MOT COMMUNICATIONS



MOT COMMUNICATION MONITOR FUNCTIONS

The systems noted here are the basic experiment equipment and the major MOT subsystems that have monitoring requirements. The number of functions or items to be monitored for each system, and the breakdown of these into telemetering requirements, are preliminary estimates. These estimates were made to establish a baseline communication system until the subsystems and experiments could be further defined. Although the numbers may change as the study progresses, the data presented is representative of what the final requirements may be for an uncoupled mode of operation.

MOT COMMUNICATION MONITOR FUNCTIONS

SYSTEM	NO. OF FUNCTIONS
CAMERA	5
SPECTROGRAPH	8
IR SPECTROMETER	8
OPTICAL SPECTROMETER	13
POLARIMETER	13
BINARY DETECTION	13
POWER	35
ATTITUDE CONTROL	210
THERMAL CONTROL	20
COMMUNICATIONS	33
RENDEZVOUS	11
CONTINGENCY	18
TOTAL	387

TELEMETRY REQUIREMENTS

40 ANALOG (2 SPS)
247 ANALOG (1 SPS)
100 DISCRETES (1 SPS)

EXPERIMENT DATA SOURCES

BINARY DETECTION (16 BIT WORD) (1 SPS)
POLARIMETRY (1 SPS)
SPECTROGRAPHY (1200 SPS)

SYNCHRONIZATION
(31 BIT WORD) (1 SPS)

MOT COMMUNICATIONS COMMAND FUNCTIONS

The same qualifications of the data presented for the Monitoring functions apply to the command functions noted on this chart. Although the number of command functions varies between modes of operations, the communications aspect of the operational requirements were not considered critical criteria for mode selection. A more complete analysis and breakdown of the functions will be prepared for the final mode of operation.

MOT COMMUNICATION COMMAND FUNCTIONS

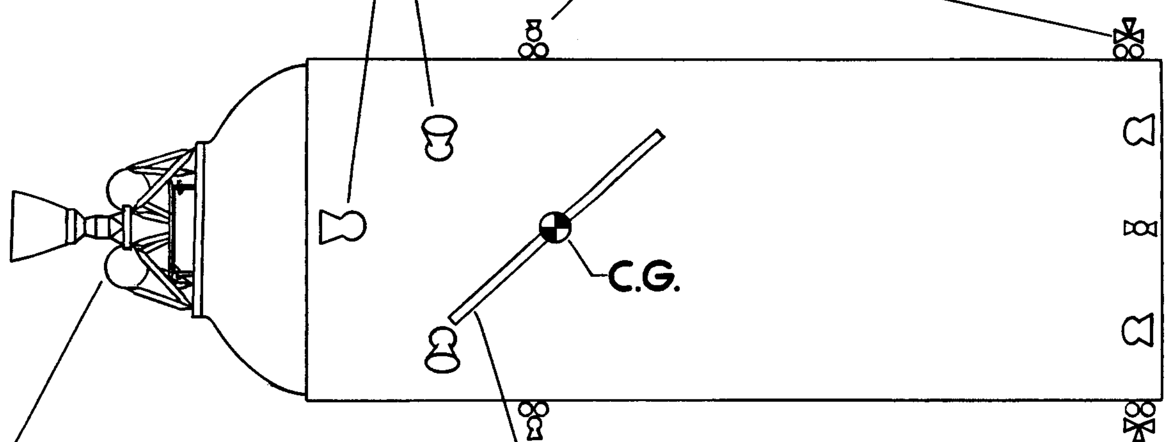
SUBSYSTEM	NO. OF FUNCTIONS
CAMERA	15
SPECTROGRAPH	30
IR SPECTROMETER	15
OPTICAL SPECTROMETER	5
POLARIMETER	4
BINARY DETECTION	5
POWER	6
ATTITUDE CONTROL	40
THERMAL CONTROL	6
COMMUNICATIONS	6
RENDEZVOUS	8
CONTINGENCY	3
TOTAL	143

PROPULSION REQUIREMENTS

The modified LEM ascent propulsion system shown is used as a launch vehicle system third stage. The initial launch and rendezvous operation assumes the S-IVB (2nd stage of the S-IB) places the MOT in a phasing or holding orbit. The S-IVB is then separated from the MOT to take advantage of the decreased mass for the hohmann transfer maneuver associated with rendezvous. The following are two possible design problem areas associated with this design concept. The type of engine and installation results in inefficient use of the space between the MOT and the top of the S-IVB and performance requirements indicate that the engine must be gimbaled. The current LEM ascent engine is a fixed-mount design. Other propulsion requirements of the MOT are handled by the smaller reaction-control jets. The four operational functions that these systems perform are attitude control, docking maneuvers, orbit keeping, and control moment gyro desaturation. The refurbishing requirements for long operation and the physical distance between jet cluster locations have led us to select self-sustained module installations. Each module would have its own tankage and pressurization and would be replaced in orbit as a unit. The installation requirements are noted in the lower right corner of the chart.

Star trackers for looking fore and aft along the telescope's optical axis should be located at the extreme ends of the structure to minimize scope interference with the field of view. The extreme ends of the structure are also ideal locations for pitch and yaw reaction jets to obtain maximum torque arms from the c.g. However, the structural servoelastic coupling study and the thermal control sutdy may show that adequate structure or minimum thermal gradients cannot be attained to mount star trackers or reaction jets at the telescope's extreme open end. Specific design installations await results of the structural servoelastic study and more defined thermal data.

PROPULSION REQUIREMENTS



REACTION JET MODULES
- ATTITUDE CONTROL
- DOCKING MANEUVERING
- ORBIT KEEPING
- CONTROL MOMENT GYRO DESATURATION

MODIFIED LEM ASCENT PROPULSION SYSTEM
- RENDEZVOUS HOHMANN TRANSFER MANEUVER
- JETTISONED BEFORE TERMINAL DOCKING

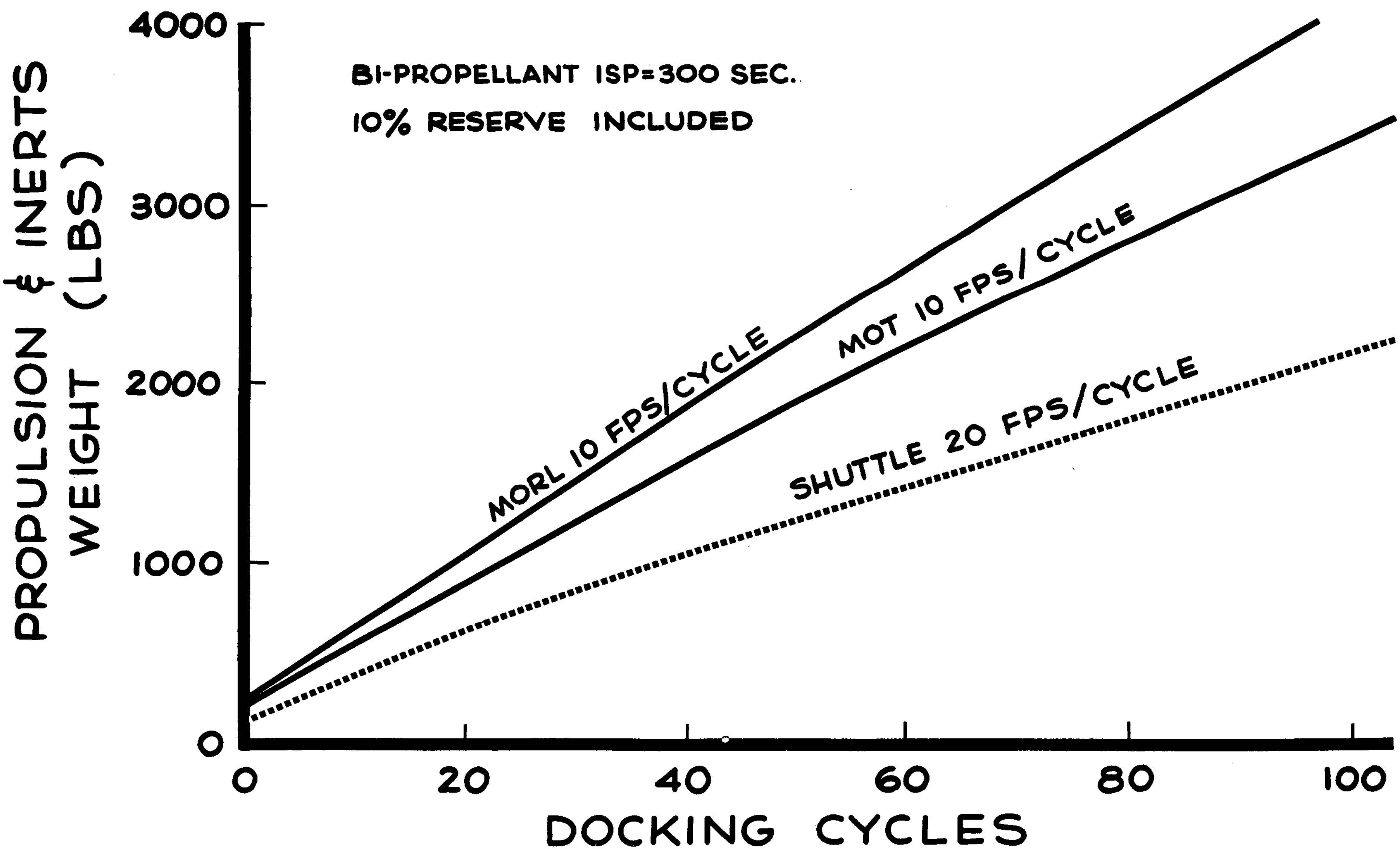
INSTALLATION REQUIREMENTS
- KEEP JET EXHAUST AWAY FROM–
  - MIRRORS
  - SOLAR PANELS
  - STAR TRACKERS
- EXHAUST SHIELDS, INSULATION & STRUCTURAL DYNAMIC REQUIREMENT
- MAINTENANCE

DOCKING PROPULSION STUDY

Repeated docking is required between the MOT and MORL for Mode IIA and IIC and also between the MOT and a shuttle vehicle for Mode IIIC. The total propellant and inert weight of the propulsion system depends on the velocity required for each docking and the number of docking cycles. In the case of MOT-to-MORL docking, either the MOT or the MORL may provide the required thrust. For MOT thrust, further detailed design analysis is necessary to determine the effect of propellant storage on the center-of-gravity offset. The MOT has volume available for about 2000 pounds of propellant storage; however, its location would be far from the vehicle center of gravity. MORL thrust, although requiring more propellant, simplifies the propellant transfer and stroage functions. Shuttle propulsion weights are based on a loaded vehicle weight of 9000 pounds. A specific impulse of 300 has been used for all systems.

MORL and MOT propulsion docking velocity requirements will be about 10 fps per cycle, assuming that a reaction control system is not required to separate the MOT and the MORL and assuming that separation distances are held to 300 to 500 feet. The shuttle vehicle, which docks twice per cycle, will require about twice the total velocity change of the MOT; however, the transfer is more efficient with regard to weight because of the much lower shuttle weight.

DOCKING PROPULSION STUDY



MODE OF OPERATION WEIGHT COMPARISON

The weights shown for the eight modes of operation were arrived at by using a centerline MOT configuration and adding or deleting the structures and subsystems that vary with each concept. The centerline configuration uses the f/4 primary mirror system and the telescoping structure design. Approximately 90 percent of the total weight is common to all modes, therefore the difference between them is of little value in selecting the best concept unless weight is a critical criteria. At present, all weights include a 20 percent growth factor and are within the Saturn IB payload capability. Expendables are a large weight factor for operation of the MOT, but in most cases this weight has to be placed in orbit and the actual choice is whether it is charged against the MORL or the MOT. In determining the launch weight, there is also a choice of whether expendables for the long initial operating period are charged against the MOT launch or against a logistic supply system. Initial supplies could easily be supplied from the MORL shortly after the MOT is placed in orbit. A 30-day onboard supply was selected for the launch weight of those concepts using independent systems. The preliminary weights used for subsystems are based on guidelines that, in general, do not overburden any one subsystem or unduly penalize any mode. Mode I concepts have slightly lower weights because they have no repeated docking requirements and are highly dependent on MORL.

MODE-OF-OPERATION WEIGHT COMPARISON
(POUNDS)

MODE NO	1A	1B	2A	2B	2C	3A	3B	3C
IN-ORBIT	23,030	24,000	26,450	25,160	26,360	24,280	26,300	25,320
START RENDEZVOUS	24,430	25,450	28,020	26,670	27,930	27,730	27,870	26,830
AT S-IVB BURNOUT	25,330	26,350	28,920	27,570	28,830	26,630	28,770	27,730
EFFECTIVE LAUNCH WEIGHT	25,890	26,910	29,480	28,130	29,390	27,190	29,330	28,290

PRELIMINARY MOT SYSTEM WEIGHTS

Preliminary weights depend heavily on the guidelines established for the operational characteristics of each system, including man's role. System weights shown are for a typical docking mode telescope (IIC). Guidelines used for each system are noted below:

Telescope Optics — Weight is shown for mirrors with cell backing structure, construction, and alignment features similar to those proposed by J. W. Fecker Division.

Experiments — Includes cameras, and fine pointing guidance equipment, 12 to 15 in number, depending upon packaging. Auxiliary launch equipment is included.

Structure — Major structural weights are the inner tube, outer tube, and 640 cubic foot cabin. Also included is docking structure, telescope and mirror doors, and boost support structure.

Thermal Control System — Thermal control weight is mostly superinsulation.

Pressurization System — Emergency atmosphere for one cabin repressurization is included. Cabin pumpdown is by the MORL system and requires about two hours.

Electronics — Electronics weights include data management, telemetry, communications, navigation, attitude control, and stabilization equipment.

Attitude Control System — Propellant is included for MOT docking to the MORL and reaction control requirements for 30 days, including 10 percent reserve, and control moment gyros for each axis.

Electrical Power — Solar panels are provided for a 1.7 kw supply. Silver-cadmium batteries are sized by initial rendezvous requirements.

Life Support System — Metabolic oxygen, suit supply connections, and replaceable purification components are provided with the emergency atmosphere system.

PRELIMINARY MOT SYSTEM WEIGHTS
(POUNDS)

TELESCOPE OPTICS	8650
EXPERIMENTS	1750
STRUCTURE	6570
THERMAL CONTROL SYSTEM	1010
PRESSURIZATION SYSTEM	100
ELECTRONICS	910
ATTITUDE CONTROL SYSTEM	1710
ELECTRICAL POWER	870
BALANCE CONTROL	300
LIFE SUPPORT SYSTEM	100
GROWTH FACTOR (20%)	4390
TOTAL IN-ORBIT WEIGHT	26,360 LB
REMOVABLE STRUCTURE *	700
EXPENDABLES	1020
MININUM OPERATIONAL WEIGHT	24,640 LB

* REMOVABLE STRUCTURE MAY BE RETAINED FOR BALLAST OR STORED & REINSTALLED FOR SPECIAL OPERATIONAL OR MAINTENANCE REQUIREMENTS.

ORBIT ALTITUDE SELECTION

A preliminary analysis was conducted of the various factors that influence the performance, design, and operation functions of the MOT over the 200 to 250 nautical mile altitude range. The data on the figure depicts the highlights of the study which resulted in the selection of a 250-nautical mile orbit altitude.

The study conclusions showed that most of the factors favored the higher altitude and are represented by the reduction in aerodynamic torque, orbit-keeping requirements, separation distance between MORl and MOT per orbit, and by a slight advantage in orbit observation time. Man's safety and launch vehicle performance were negative factors as they resulted in a combined weight penalty of about 1150 pounds for MOT. Weight is currently not a critical item, therefore the decision favored better telescope performance and operation.

The slight advantage in observation time is because 50 percent of the total moonless-night sky radiation is produced by photochemical processes in the Earth's ionosphere and the 250 nautical mile orbit places MOT 50 miles above the ionosphere.

The vehicle separation curve shows that the difference in ballistic coefficients between MORL and MOT are strong factors as well as orbital altitude difference. There is no separation when the ballistic coefficients of the two vehicles are equal. Therefore, the curve crosses the space station ordinate at 23.2 psf — the average coefficient used for the MOT. Separation distance is plotted as both positive and negative to show whether MOT is drifting behind of head of MORL. Note that this curve can only be used for one or two orbits as the separation then increases rapidly.

ORBIT ALTITUDE SELECTION

250 NM ORBIT SELECTED OVER 200 NM ORBIT

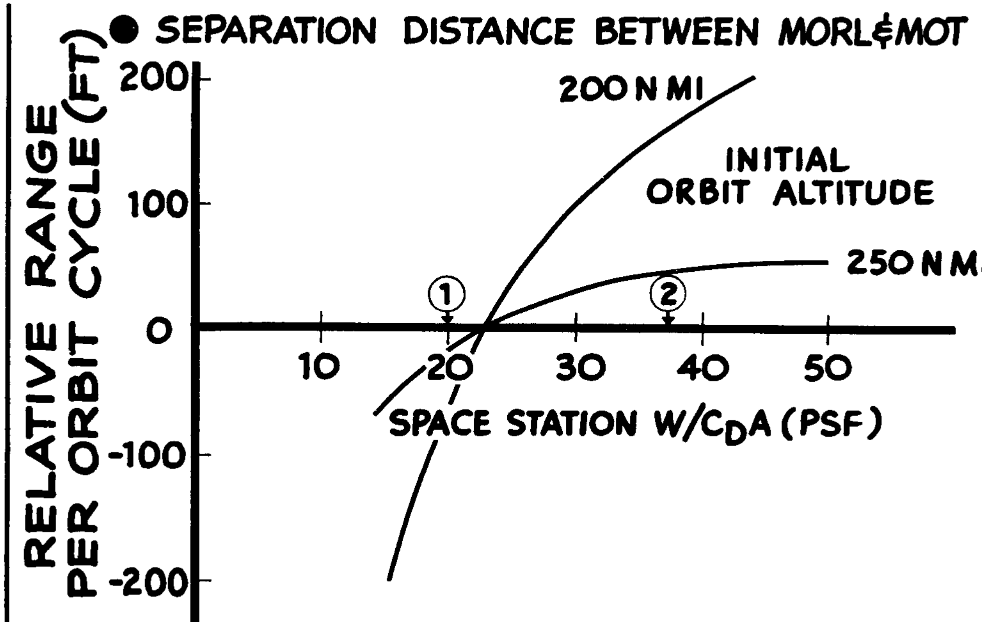
- SLIGHT ADVANTAGE IN OBSERVATION TIME

- REDUCTION IN AERODYNAMIC TORQUE
  0.098 FT-LBS TO 0.024 FT-LBS

- REDUCTION IN ORBIT KEEPING REQUIREMENTS

- 1150 LB MOT WEIGHT PENALTY DUE TO RADIATION PROTECTION & DECREASE IN BOOSTER PAYLOAD

- SEPARATION DISTANCE BETWEEN MORL & MOT



① MORL TRAVELING ENDWISE (AVG)

② MORL TRAVELING SIDEWAYS (AVG)

- MOT AVERAGE W/C_DA = 23.3 PSF
- 1962 U S STD ATM

CONTROL OF OPTICAL GEOMETRY

FACTORS AFFECTING OPTICAL GEOMETRY

If the telescope is to operate with diffraction-limited performance, the first requirement is that the figure of the primary mirror be kept within its optical shape to approximately 1/20 of a wavelength. The actual value of this limit depends on the number of reflecting and refracting surfaces in the telescope system. The second requirement is that the primary and secondary mirrors be properly positioned with respect to each other. The accuracy to which this must be done depends on the focal ratio of the primary mirror and the equivalent focal ratio of the telescope.

Both of these basic requirements will be difficult to satisfy because of geometrical errors of several kinds. Initially, manufacturing errors and tolerances are introduced. Boost imposes forces which may cause inelastic deflections, as may the change to zero gravity. It is also possible that the mirror will be operated at a temperature different than that at which it was manufactured, giving rise to another possible inelastic deformation. Temperature gradients will cause thermoelastic deformation, and finally, it is possible that deformation may occur from long-term stress relaxation.

Of these possible errors, only the problem of temperature gradients has been studied. However, the other errors mentioned are also important, and must be studied before feasibility of diffraction-limited operation can be assured.

FACTORS AFFECTING OPTICAL GEOMETRY

REQUIREMENTS :

- FIGURE OF PRIMARY MIRROR – $\lambda/20$ AT 5600 Å
- POSITIONING OF PRIMARY WITH RESPECT TO SECONDARY– FOCAL RATIO

GEOMETRICAL ERRORS CAUSED BY :

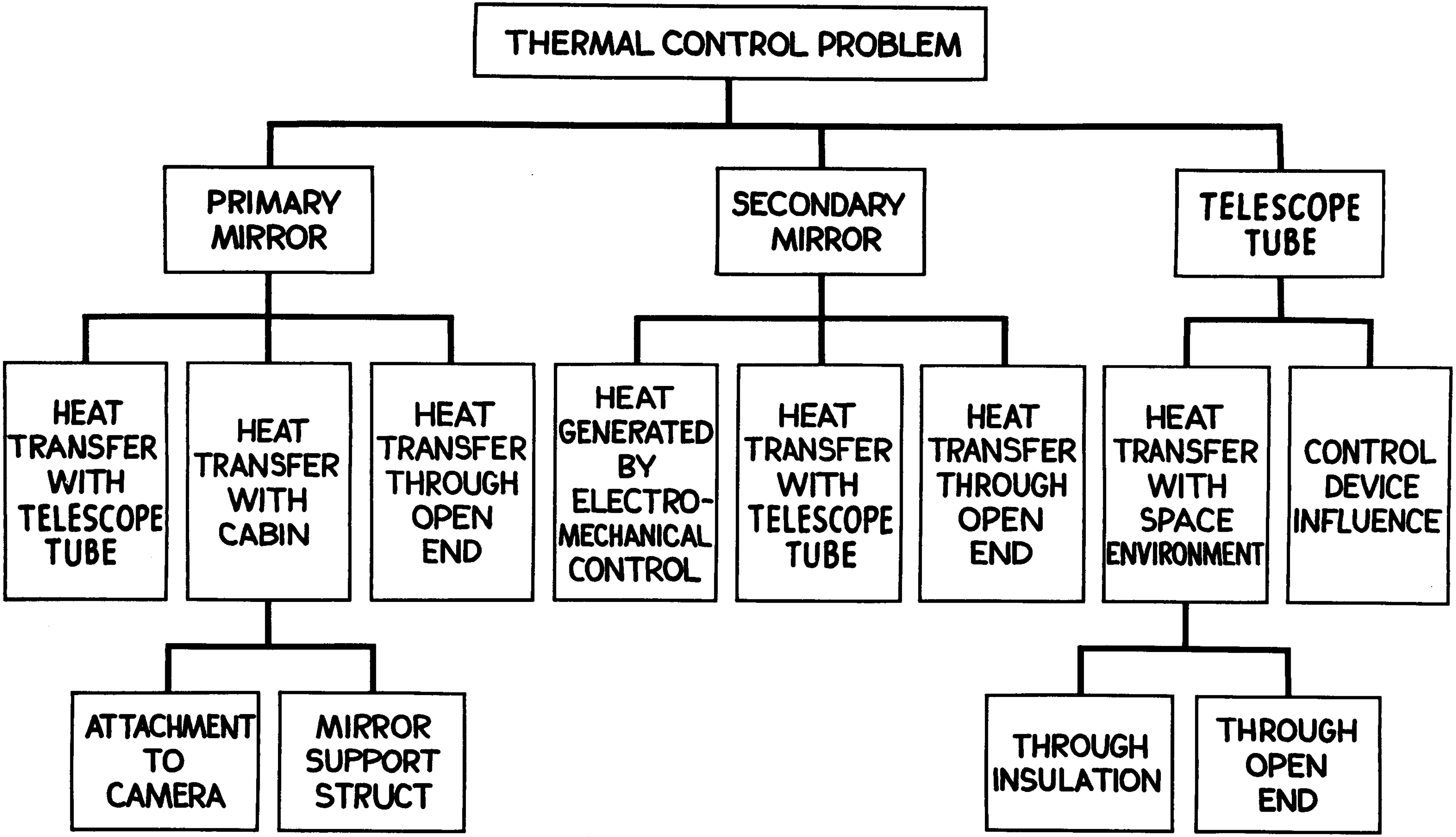
- MANUFACTURING ERRORS
- BOOST DEFORMATION
- CHANGE IN GRAVITY
- OPERATING TEMP. $\neq$ MFG. TEMP.
- TEMPERATURE GRADIENTS
- LONG TERM STRESS RELAXATION

BREAKDOWN OF TELESCOPE HEAT TRANSFER MODES

The thermal control problem may be broken down into several major heat transfer modes. Since extremely fine temperature control is desired, each mode is potentially a major problem and therefore must be analyzed before feasibility can be definitely established.

The thermal effect on three major structural members must be considered. These are the primary mirror, the secondary mirrors, and the telescope tube. Principal emphasis has been given to thermal control of the primary mirror. The thermal control of the telescope tube is also very important because of its effect on the positioning of the secondary mirror and because of temperature gradients induced in the primary mirror. Thus far, relatively little effort has been expended on thermal control of the secondary mirror because it appears that this requirement could be met with less difficulty than the requirement for thermal control of the primary mirror.

BREAKDOWN OF TELESCOPE HEAT TRANSFER MODES



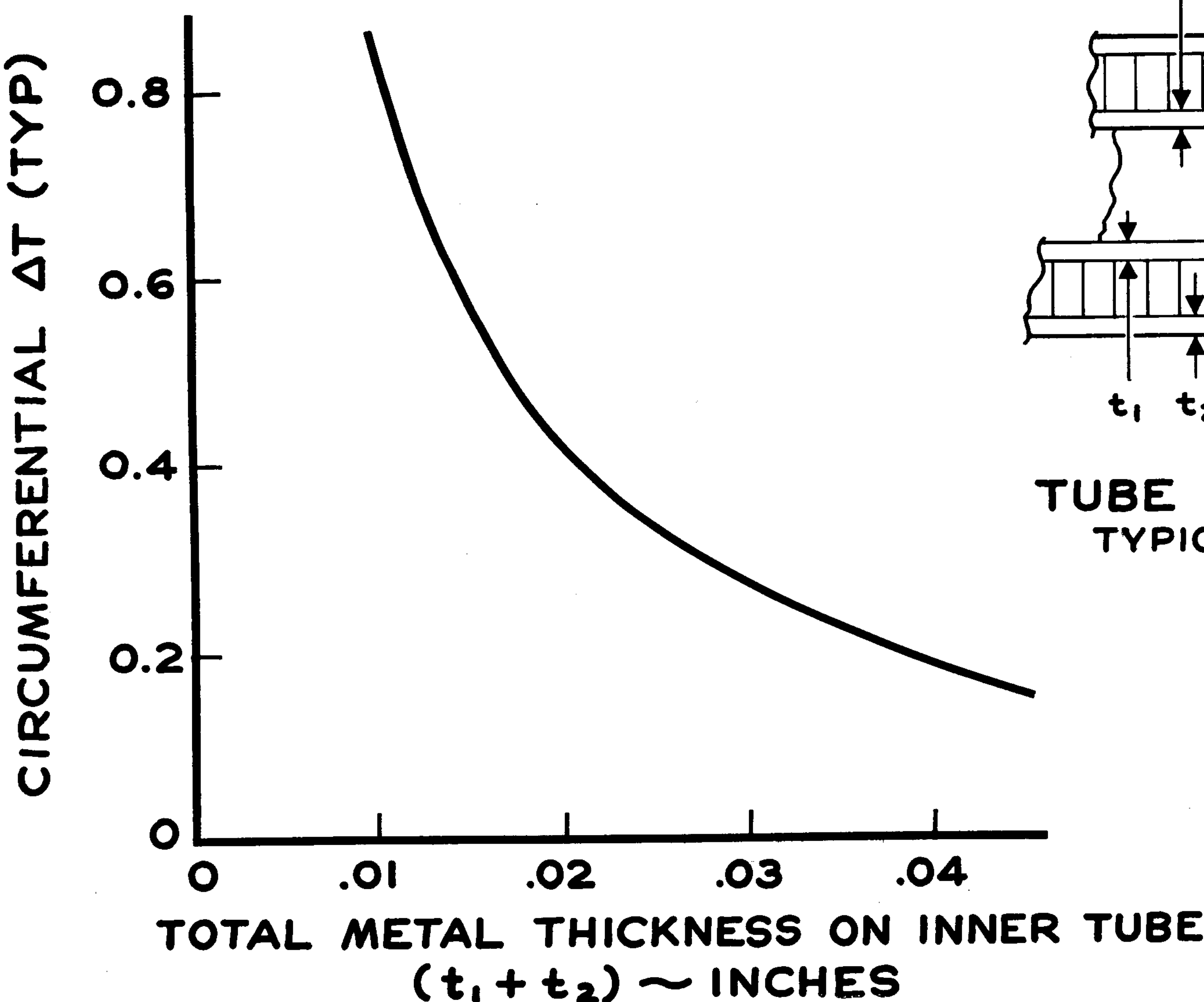
PREDICTED CIRCUMFERENTIAL ΔT

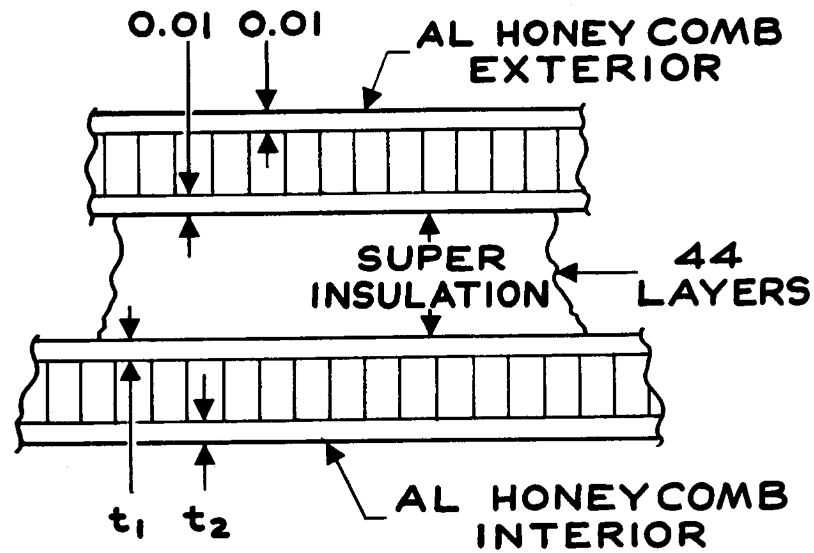
This figure shows typical temperature gradients that occur on the interior surface of the telescope tube. The data shown here are based on the model consisting of two concentric tubes separated by superinsulation and were taken at the midpoint of the tube length. No attempt was made to optimize any of these dimensions or design features, but even so, temperature differentials of less than one degree Fahrenheit should be attainable.

The principal reason for exploring these data is to see if the temperature differences from one side of the tube to the other are small enough so that it will be possible to use a single-axis control on the secondary mirror. Subsequent data will show that these temperature differentials are small enough to make single-axis control feasible.

Another reason for keeping this gradient small is to prevent temperature nonuniformities in the primary mirror. To do this, it may be necessary to optimize dimensions and design features of the tube to reduce gradients even further, especially near the primary mirror.

PREDICTED CIRCUMFERENTIAL ΔT





TUBE WALL SECTION
TYPICAL SCHEMATIC

- f/4
- 23° INCLINATION
- AXIS ⊥ ORBIT PLANE & SOLAR VECTOR

SECONDARY MIRROR SUPPORT STRUCTURE

Permissible Circumferential ΔT

f/2 and f/4 Mirror

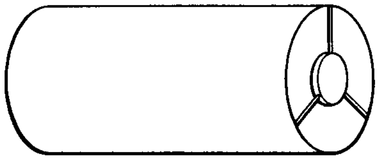
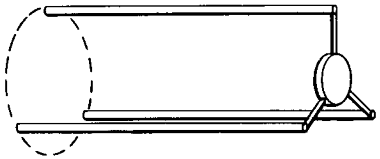
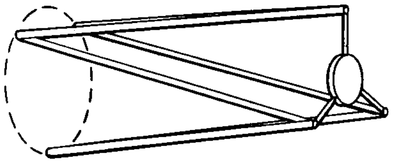
Three structural concepts for secondary mirror support were studied. These represent the structural tie between the primary and secondary mirrors. The three concepts, a semi-monocoque cylinder, a linear support using three tubes, and a six-bar determinate truss, are shown on the left. The materials studied, including 2024 aluminum and 5Al-2.5Sn, are listed opposite the configurations to which they were applied.

The results of the analysis show the maximum allowable temperature difference across the diameter of the structure based on a temperature gradient that is linear with the diameter. The operating temperature level also is important primarily because of the change in coefficient of thermal expansion with temperature. The ΔT limits on which these results are based were established by the following tolerances on secondary misalignment: 0.0008-inch and 0.007-inch lateral misalignment and 5 and 13 second angular misalignment for the f/2 and f/4 mirrors, respectively. Lateral misalignment is found to be the more severe condition in all cases except the three-tube tie, which is limited by angular misalignment.

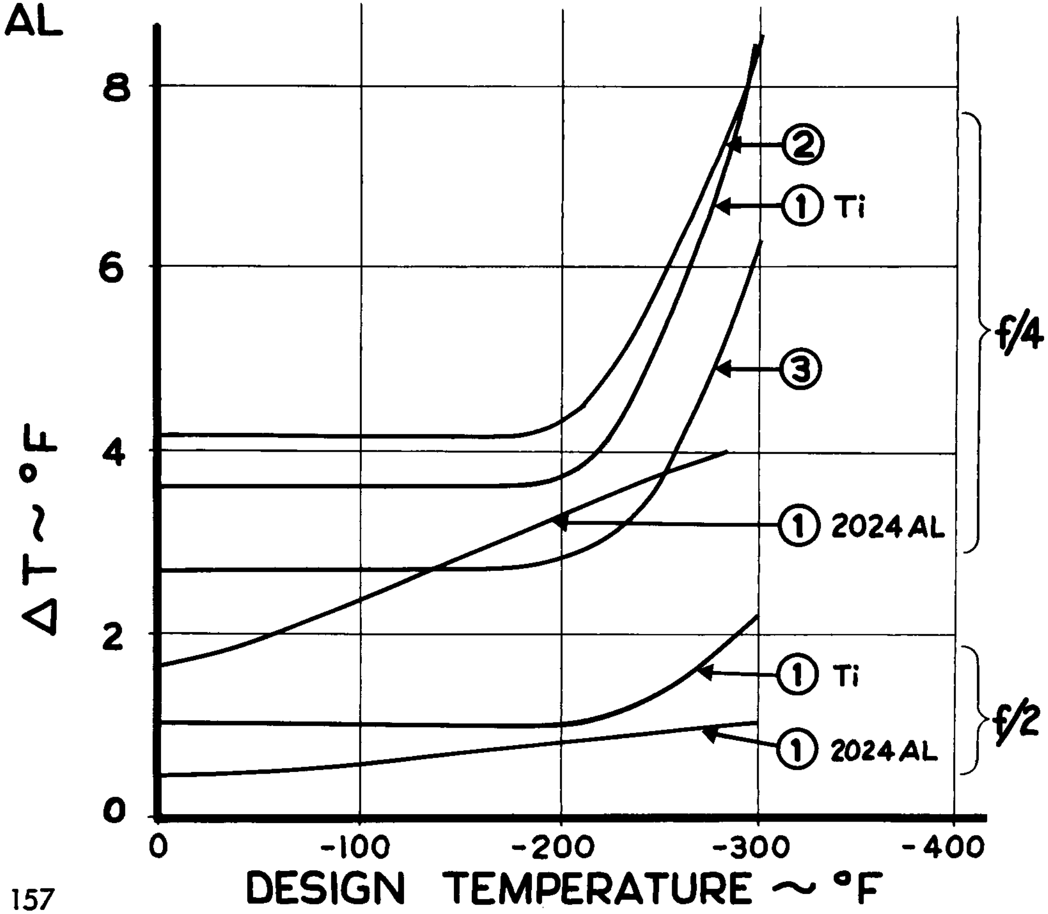
Thermal analysis indicates that it is practical to hold the support structure for the f/4 mirror within these limits for any of the structural concepts shown. The f/2 mirror, having closer tolerances than the f/4, has a narrower band of allowable temperature differentials than the f/4. Thus it can be seen that when the optical and thermal tolerances are considered jointly the choice is in favor of the f/4 primary mirror configuration.

SECONDARY-MIRROR SUPPORT STRUCTURE

PERMISSIBLE CIRCUMFERENTIAL ΔT f/2 & f/4 MIRROR

SUPPORT CONCEPT		MATERIAL
① CYLINDER		Ti & AL
② THREE TUBE		Ti
③ SIX BAR TRUSS		Ti

PERMISSABLE GRADIENT



CONCLUSIONS ON SECONDARY MIRROR CONTROL

The main conclusions to be drawn from the studies on secondary mirror control are:

<u>An f/4 primary is superior to an f/2 primary from the standpoint of thermally induced misalignment</u>. This results primarily from the much closer tolerances that must be held but also because it will be harder to produce uniform temperature control in the short telescope tubes associated with an f/2 primary.

<u>A cylinder support is structurally and thermally satisfactory</u>. Even if there were no thermal considerations, a cylinder would be a good design structurally. Since a cylinder will also help to equalize circumferential and axial temperature gradients, such a design is considered a good choice.

<u>Single-axis control is feasible</u>. Maximum permissible temperature gradients to support the secondary mirror within the dimensional and angular tolerances were determined. It was found that the expected temperature differences were within these tolerances.

<u>With single-axis control, initial alignment in 5 degrees of freedom is needed</u>. Even though the tolerances in tilt and lateral displacements should not be exceeded, it will be necessary to monitor these displacements and, if necessary, make adjustments.

CONCLUSIONS ON SECONDARY MIRROR CONTROL

- f/4 PRIMARY IS SUPERIOR TO f/2 FROM A STANDPOINT OF THERMALLY INDUCED MISALIGNMENT
- A CYLINDER SUPPORT IS SATISFACTORY STRUCTURALLY & THERMALLY
- SINGLE AXIS CONTROL IS FEASIBLE
- WITH SINGLE AXIS CONTROL, NEED INITIAL ALIGNMENT IN FIVE DEGREES OF FREEDOM

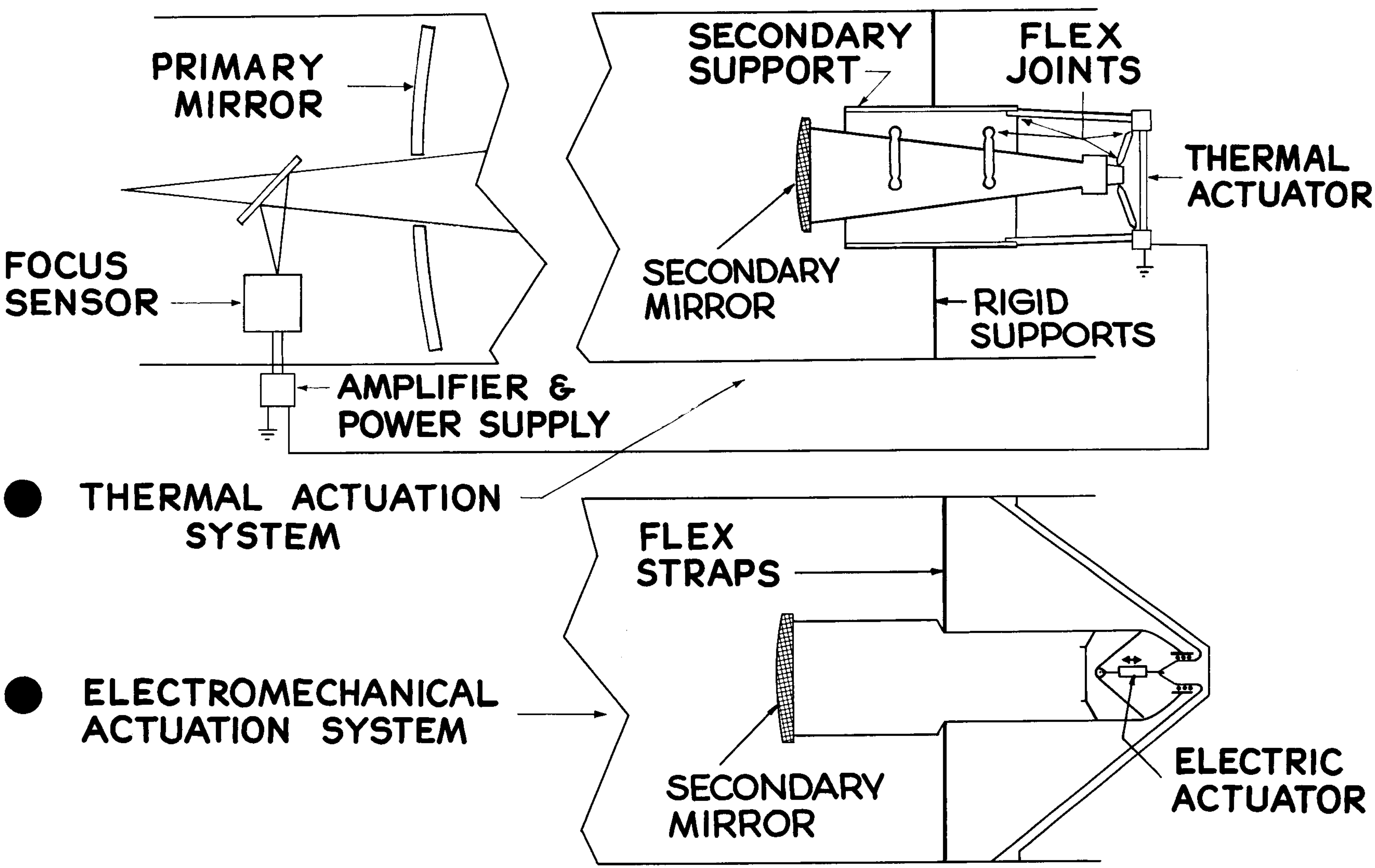
TYPICAL SINGLE-AXIS FOCUS CONTROL SYSTEM

As the temperature of the telescope interior changes, the structure will deform, requiring focus adjustment. This figure shows two possible mechanizations for periodically monitoring and automatically adjusting the focus.

The upper system is composed of a focus sensor, a thermal actuator, and a flexible truss support for the secondary mirror housing and actuator. In operation, the system will maintain focus as follows: the focus sensor will signal an error; the error signal will be amplified and introduced to an electric current generator; the current will flow in a heater in the thermal actuator; as the thermal actuator changes length, the support truss will change shape slightly, causing the secondary mirror housing to translate relative to its support structure, and the error signal is reduced. The focus sensor operates by periodically inserting a mirror into the gathered light beam. The deflected light passes through optical elements to photomultipliers which measure and compare light gathered a fixed distance ahead of and behind the focal plane. This generates a focus error signal.

A typical thermal actuator would be designed to control to the focus tolerance over a total deflection range of 0.12 inch. This requires a 64°F actuator temperature range, 26 watts average power with 36 watts maximum, and will take about ten minutes to travel full stroke (contracting). Another possible system would utilize an electric screw jack actuator geared down by means of linkage to provide the necessary resolution. This system is nearly as simple and could utilize off-the-shelf components.

TYPICAL SINGLE AXIS FOCUS CONTROL SYSTEMS



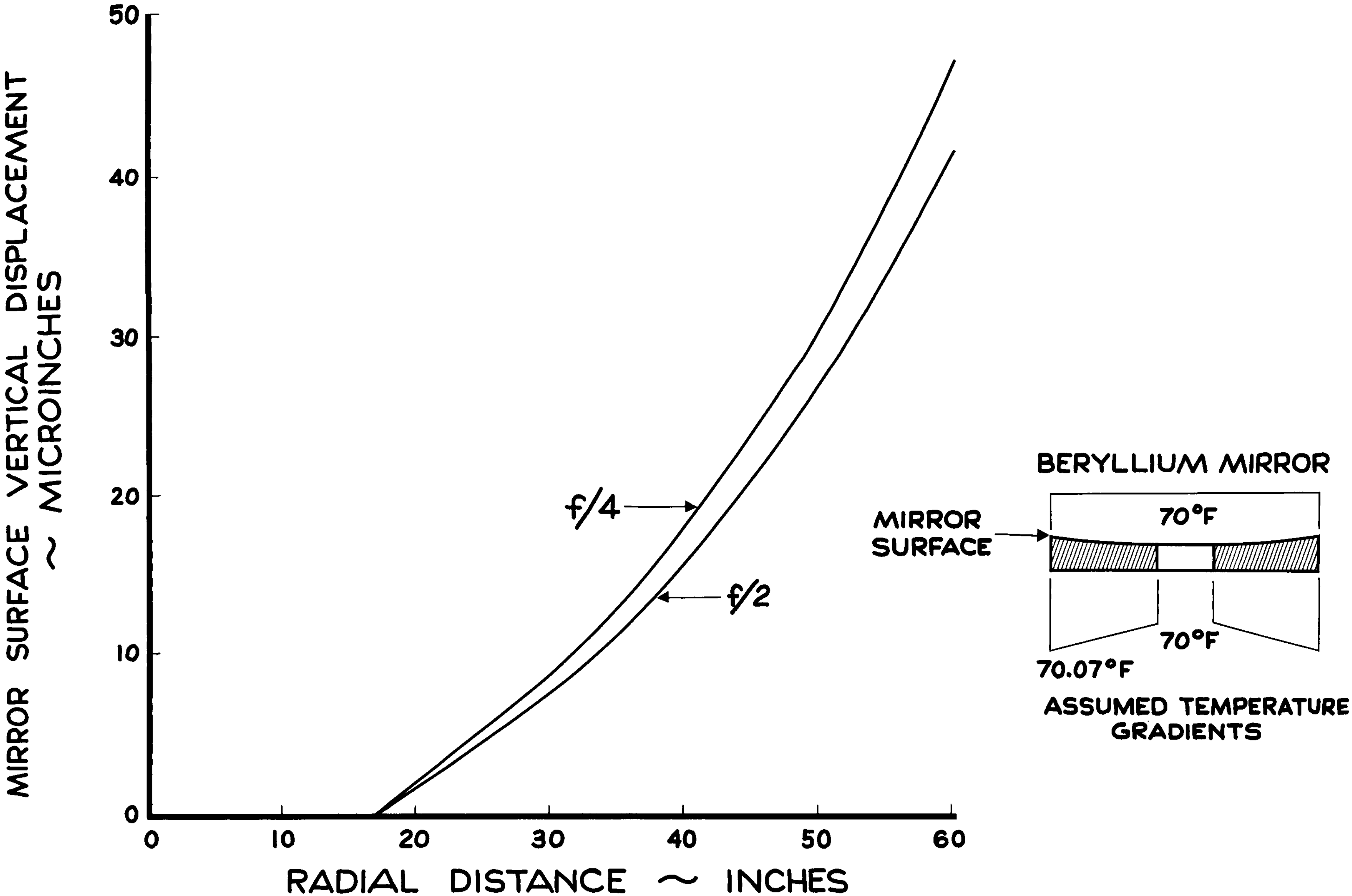
THERMAL DEFORMATION OF PRIMARY MIRROR

This figure shows the effects of a radial thermal gradient assumed on the back of the primary mirror. Surface point deflections in the vertical are given for f/2 and f/4 mirrors as functions of radial station, thus permitting a comparison of the two mirror figures. Results are based on a beryllium honeycomb mirror similar to that recommended by the Fecker study.

A computer program utilizing the direct stiffness method developed at Boeing was employed to obtain deformations. Since this temperature gradient produces a stressed condition of the mirror material, these deformations cannot be scaled to other operating temperatures or materials.

It may be noted that radial as well as vertical deflections will appear. However, the radial deflections are not as optically harmful and so are not shown. With a permissible figure tolerance of 1 microinch it can be seen that a potentially severe problem exists.

THERMAL DEFORMATION OF PRIMARY MIRROR

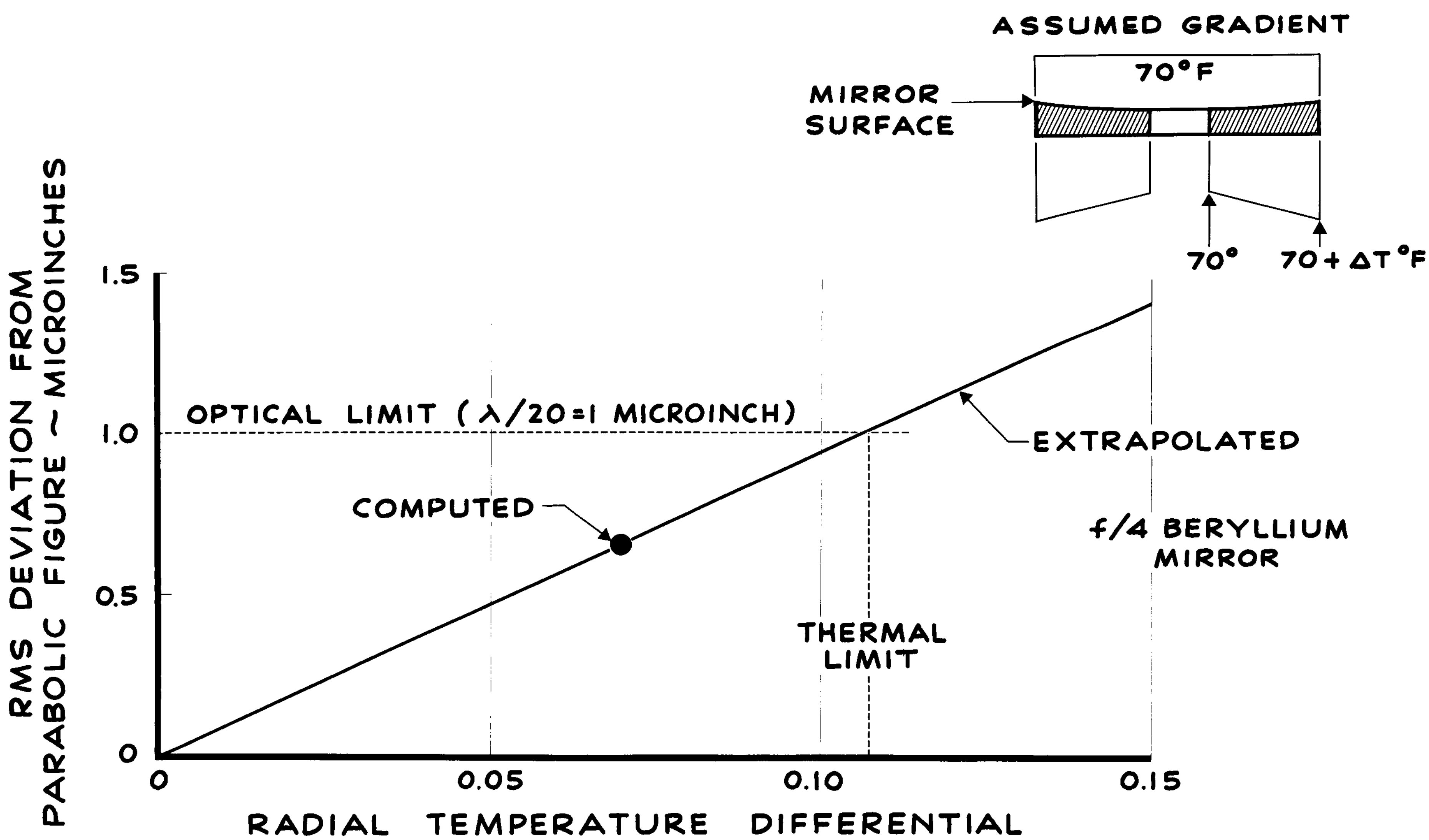


DEVIATION OF PRIMARY MIRROR FIGURE DUE TO TEMPERATURE

The previous figure showed that a linear temperature gradient applied to the back of the primary mirror would cause large vertical displacements on the optical surface. If this deflection were to result in a different but still perfect parabolic shape, the focus control would adjust to it and no error would result. If the new shape is not a perfect parabola, then the error will be approximately the RMS deviation of the best parabola that can be fitted to the new shape.

This chart shows the results of such an exercise of fitting a new parabola to a mirror with axisymmetrical thermal distortions. One point was calculated using the data shown in the previous illustration, and from this point the straight line was extrapolated. Though the temperature distribution imposed was assumed, this type of calculation gives some idea of the relationship between temperature gradient and mirror figure error. Using the calculated point as an example, the RMS deviation of the new parabolic shape is 0.646 microinches compared with an average deflection of approximately 30 microinches, a reduction by a factor of 45. The relationship between temperature gradients of different types and the resulting error in the mirror figure is not known at this time and must be explored more fully in the latter half of the study.

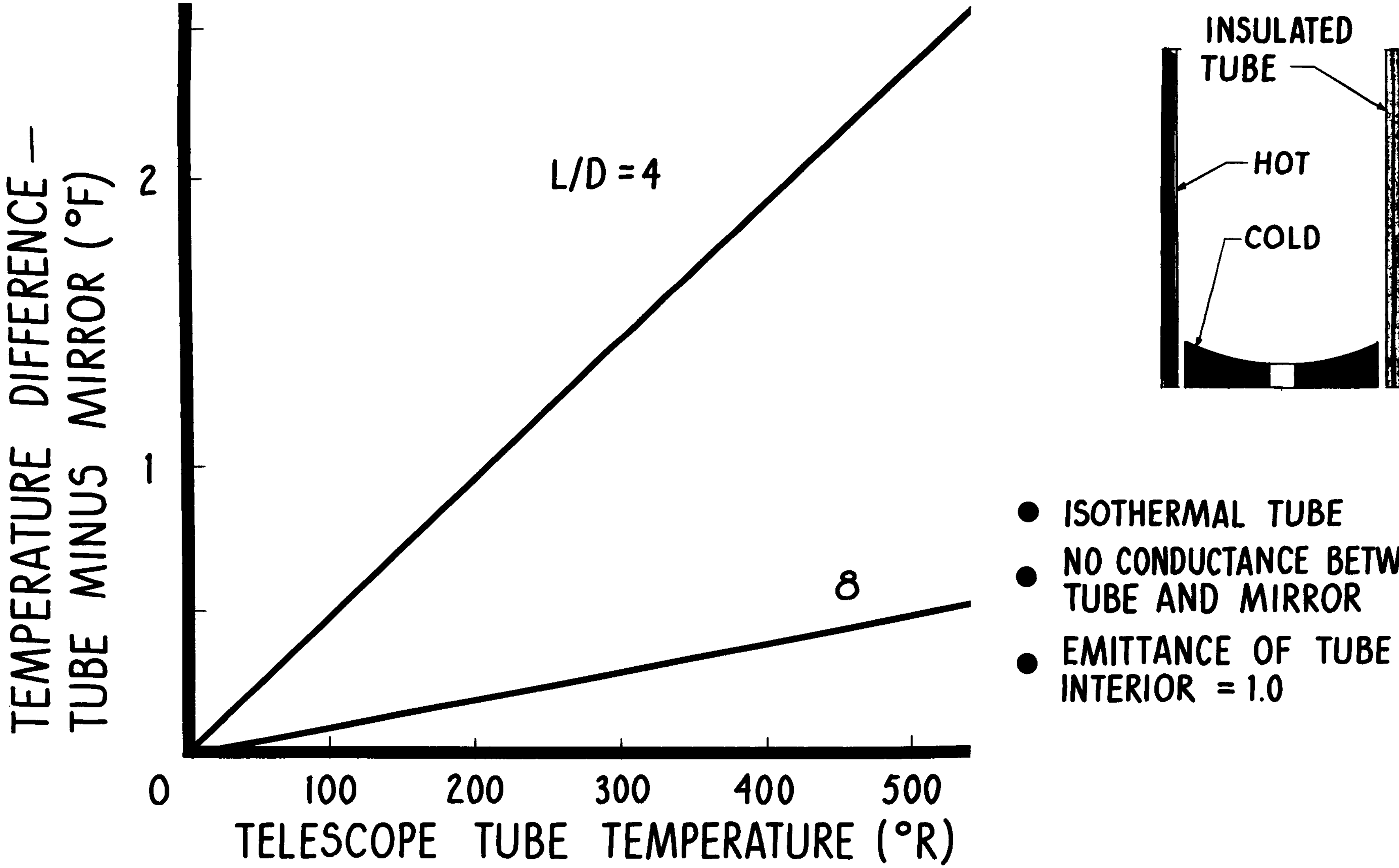
DEVIATION OF PRIMARY MIRROR FIGURE DUE TO TEMPERATURE



TEMPERATURE DIFFERENCE BETWEEN PRIMARY MIRROR AND TELESCOPE TUBE

Some temperature gradient in the primary mirror will result from the fact that the primary mirror and the telescope tube are not at the same temperature, even if the telescope tube is isothermal. The magnitude of this effect is shown in the accompanying chart and is a consequence of the cylindrical geometry used for the MOT and its resulting view factors between the mirror, telescope tube, and space. It is seen that this effect is less at low operating temperatures and long tube lengths. The temperature gradient from this cause may be reduced by providing a low conductivity support system for the primary mirror.

TEMPERATURE DIFFERENCE BETWEEN PRIMARY MIRROR & TELESCOPE TUBE

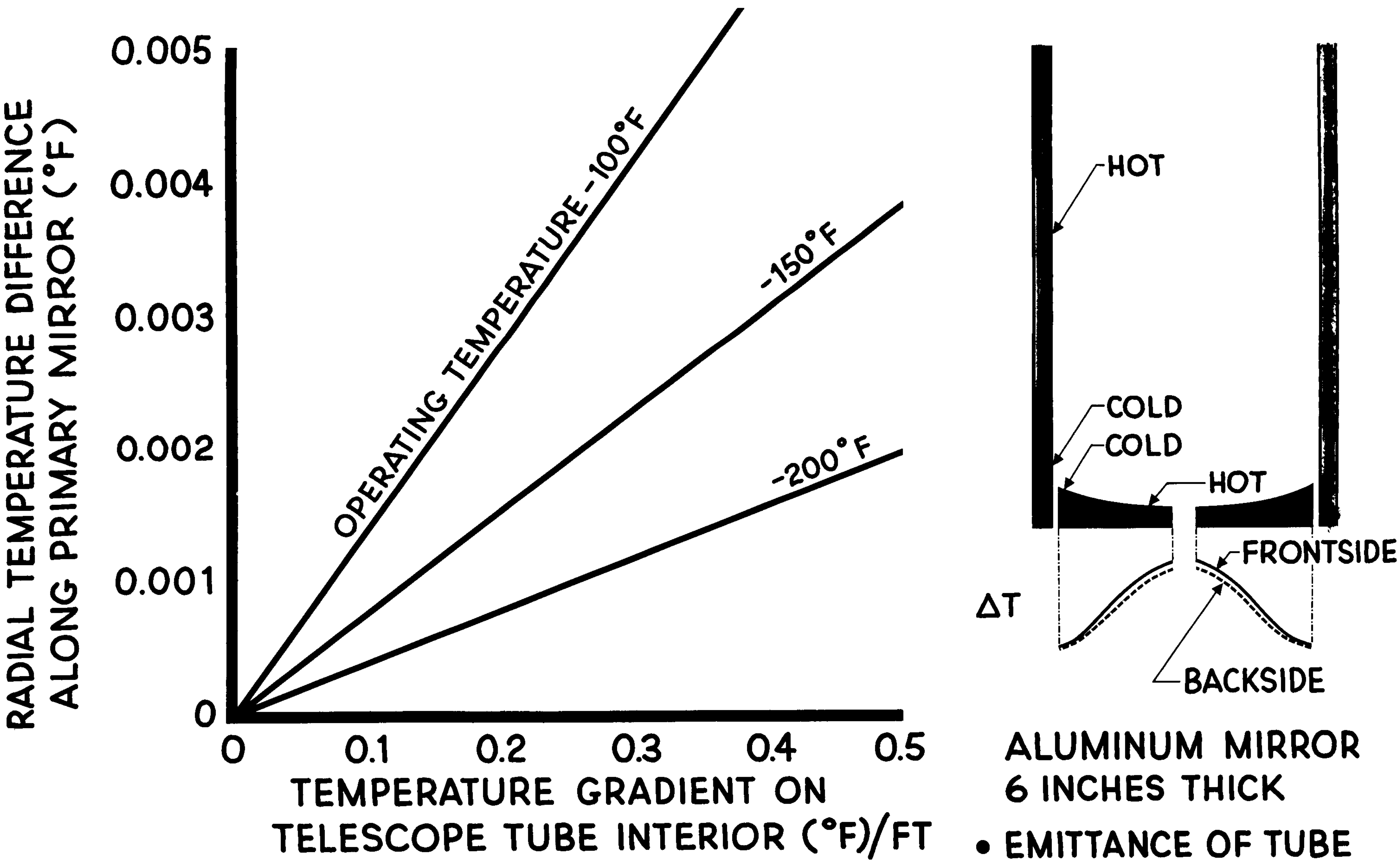


- ISOTHERMAL TUBE
- NO CONDUCTANCE BETWEEN TUBE AND MIRROR
- EMITTANCE OF TUBE INTERIOR = 1.0

EFFECT OF NONUNIFORM TELESCOPE TUBE TEMPERATURE ON PRIMARY MIRROR

Another cause of temperature gradients in the primary mirror results from an axial temperature gradient in the inner telescope tube. If that portion of the inner telescope tube nearest the telescope aperture is heated by reflected or emitted Earth radiation, then an axial gradient will be established in the tube with lower temperatures near the primary mirror. This axial gradient in the telescope tube will induce a radial gradient in the primary mirror which must be held within acceptable limits. It is evident from the accompanying figure that tube surface temperatures nearest the mirror will have the most pronounced effect on mirror temperature gradients due to the greater view factor. If the mirror is assumed to be insulated at the edges, an S-shaped radial temperature gradient occurs. Again, it will be noted that the temperature gradients are diminished at lower operating temperatures.

EFFECT OF NONUNIFORM TELESCOPE TUBE TEMPERATURE ON PRIMARY MIRROR



ALUMINUM MIRROR 6 INCHES THICK

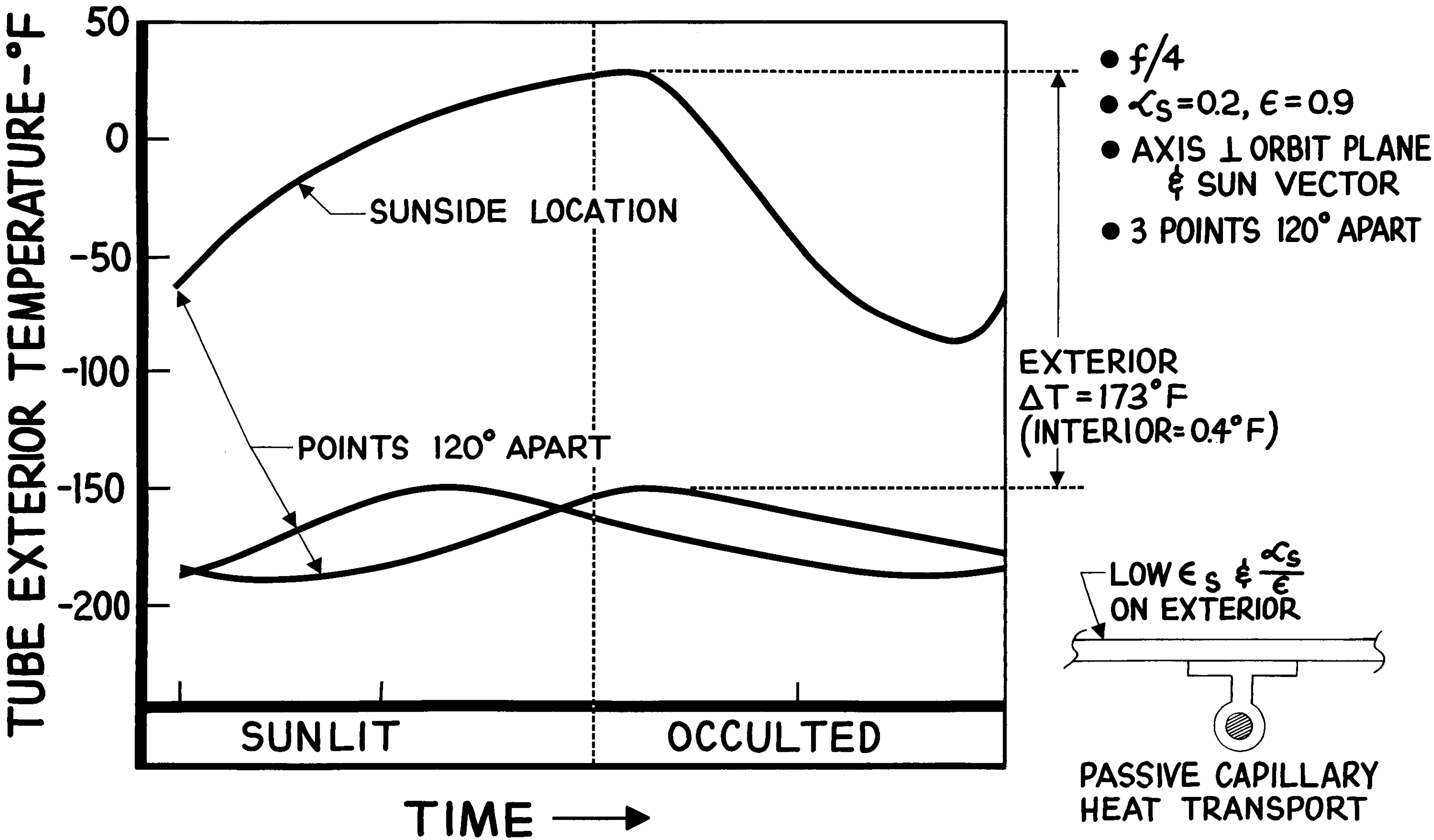
- EMITTANCE OF TUBE INTERIOR = 1

TELESCOPE TUBE EXTERIOR TEMPERATURES

It has been shown that the circumferential temperature gradient in the inner telescope tube is small enough to permit single-axis positioning control. However, this circumferential gradient in the tube may still be great enough to produce an undesirable circumferential gradient in the primary mirror. The effect may be reduced by choosing an exterior surface coating having the properties of low emissivity and a low ratio of solar absorptivity to infrared emissivity. Temperature gradients on the exterior tube may be reduced also by using a tube material of high thermal conductivity and of sufficient thickness to conduct heat to cooler portions of the tube. The circumferential temperature gradient in the inner tube may also be greatly reduced if the outer tube is effectively insulated from the inner tube using multilayer vacuum insulation.

The passive capillary heat transport system shown in the illustration offers a further means of achieving a more uniform temperature distribution.

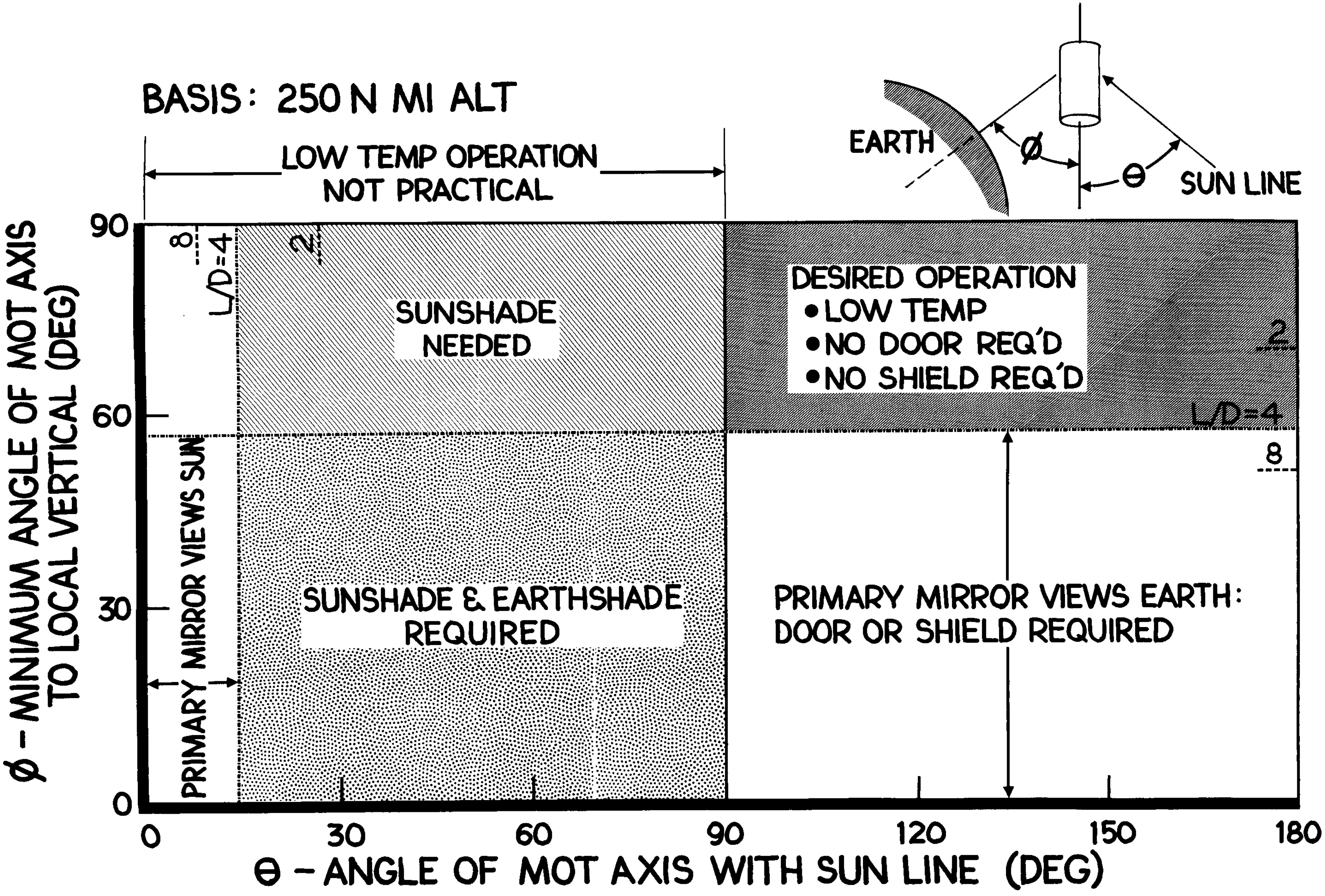
TELESCOPE TUBE EXTERIOR TEMPERATURES



POTENTIAL ATTITUDE LIMITATIONS

A basic objective in the design of the MOT is to achieve as much operational flexibility as possible. It is therefore desired that the thermal control system have the capability of functioning properly for all orbits and orientations. A definite exception is that direct sunlight shall not be permitted to strike the primary mirror. Other practical limitations from a thermal standpoint are that the primary mirror shall not view the Earth, nor shall sunlight enter the telescope tube. Different regimes of telescope orientation are shown together with the basic difficulty each poses on the thermal control system. It is evident from this operational map that doors, shields, or other devices may be required at the telescope tube opening to attain maximum operating flexibility.

POTENTIAL ATTITUDE LIMITATIONS



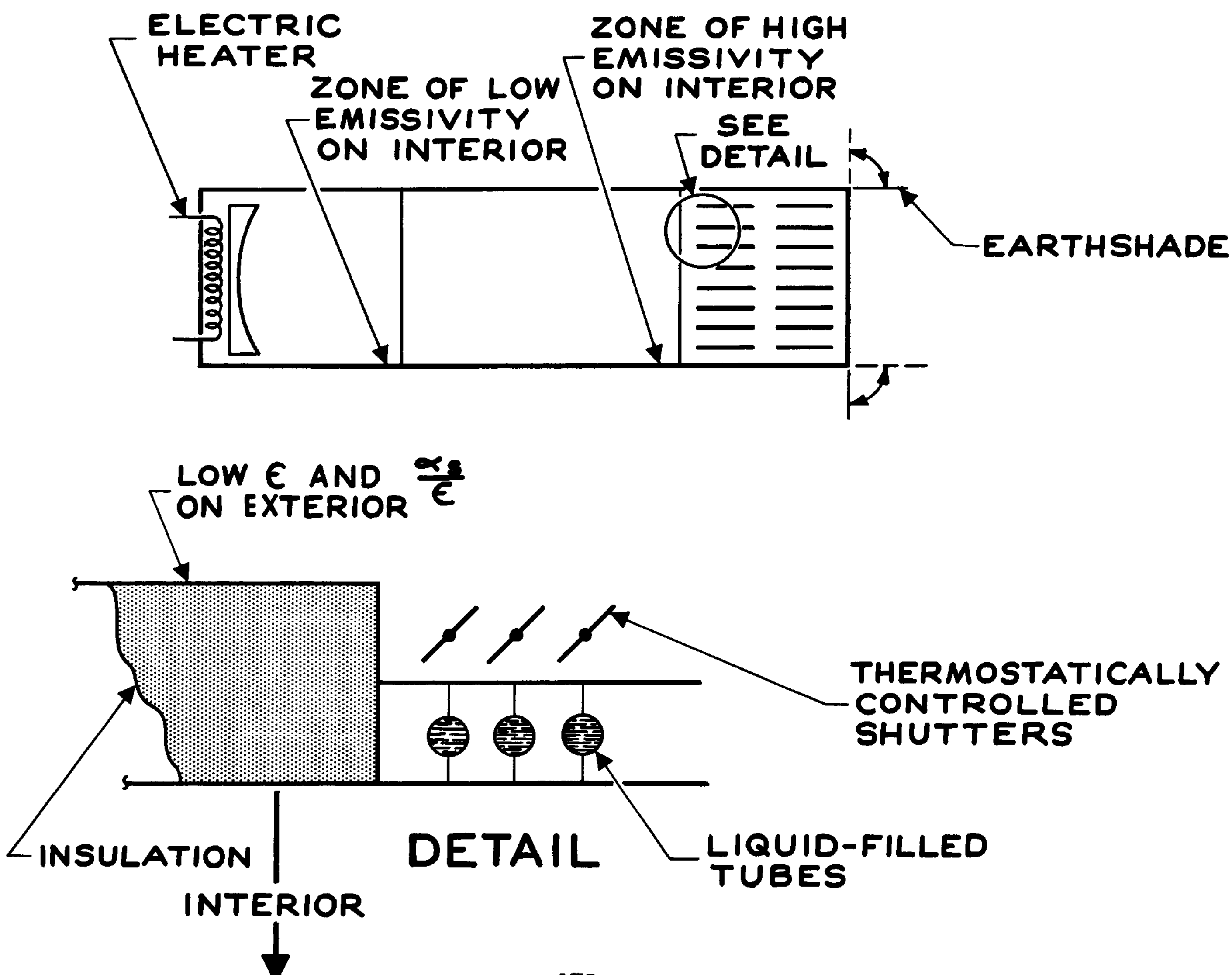
TYPICAL SEMIPASSIVE TEMPERATURE CONTROL SYSTEM

These are some of the ideas being considered in the design of the temperature control system. Our approach has been to control by passive means if possible and, where necessary, determine the need and extent of active systems. A number of thermal problems have been identified by computer analyses and parametric studies and the thermal design is being revised accordingly.

The objects of the system shown are to provide as much thermal isolation as possible for the primary mirror, and to make the telescope tube as nearly isothermal as possible. One concept is to use a device at the end of the tube which will control that section to some particular temperature. This device would dampen the short-term temperature perturbations of each orbit by means of thermal mass, and would control the average temperature over many orbits by devices such as shutters which would adjust only to the long-term changes.

A heater is also shown on the back of the primary mirror that could be used either to equalize temperature gradients and produce a more nearly isothermal design, or could be used to correct the figure of the mirror due to other errors. The control could be passive, employing a fixed heat input, or active in which the heat input is variable and depends on an information-sensing system for its control.

TYPICAL SEMI-PASSIVE TEMPERATURE CONTROL SYSTEM



MAJOR UNSOLVED THERMAL PROBLEMS

Among the major unsolved problems is the establishment of requirements for the primary mirror. A mirror material and design must be selected that is less affected by temperature variations. Also of interest is the preferred operating temperature, effect of temperature cycling, and the deviation from a true paraboloidal shape resulting from temperature cycling and gradients.

The thermal gradients in the primary mirror must be held to a minimum by careful design, and further analysis should be made of the gradients resulting from radiation from the tube and conduction at the mirror attachment points.

Other problem areas include the determination of temperature gradients in the secondary mirror, and temperature control of the structure to maintain proper positioning of the optical elements. To increase operational flexibility, the use of Sun and Earth shades should be studied.

MAJOR UNSOLVED THERMAL PROBLEMS

- REQUIREMENTS ON PRIMARY MIRROR
  - WHAT IS A GOOD MIRROR MATERIAL & DESIGN ?
  - IS THERMAL CYCLING TOLERABLE ?
  - RELATIONSHIP BETWEEN REAL GRADIENTS & ERRORS ON NEW SHAPE
- THERMAL GRADIENT IN PRIMARY MIRROR
  - RADIATION WITH TUBE
  - HEAT TRANSFER FROM CABIN
  - HEAT TRANSFER AT ATTACHMENT POINTS
- THERMAL GRADIENTS IN SECONDARY MIRROR
- TEMPERATURE CONTROL OF SECONDARY MIRROR SUPPORTS
- GEOMETRIC RELATIONSHIP BETWEEN PRIMARY MIRROR & EXPERIMENT BOXES
- USE OF DOORS IN THERMAL DESIGN

ATTITUDE CONTROL & STABILIZATION

STABILITY AND CONTROL REQUIREMENTS

During its mission duration, the MOT GC &SS/Guidance Control and Stabilization Subsystem is required to perform several functions. Target acquisition is the first of these.

Subsequent to being placed in orbit by its own unmanned booster, the MOT must be oriented for rendezvous and/or orbit corrections. Once this has been accomplished the MOT must be capable of maneuvering to and pointing at a selected celestial target within very tight accuracy tolerances. To accomplish the maneuvering and pointing missions, as many as three levels of sensors may be required. The coarse and intermediate accuracy sensors should pose no extreme technical problems and were combined under the target acquisition category.

In contrast, the fine pointing mode is thought to present a sizable technical challenge. In this mode three main types of targets are encountered: on axis, where the target is bright enough to permit its use as a guide star; off axis, where the target is not bright enough to permit its use as a guide star; and planetary tracking, where the target may be too large to permit its use as a guide.

STABILITY & CONTROL REQUIREMENTS

TARGET ACQUISITION

- INITIAL STABILIZATION
- SLEWING – 5 DEGREES IN 2 MINUTES
- COARSE POINTING – TO 3 MINUTES OF ARC
- INTERMEDIATE POINTING – TO 5 ARC SEC

FINE POINTING

ON AXIS

- HOLDING ACCURACY – 0.01 ARC SEC
- 45-MINUTE DURATION
- 10TH MAGNITUDE STARS

OFF AXIS

- STABILIZATION – 0.01 ARC SEC
- ACCURACY – 1 ARC SEC
- 45-MINUTE DURATION
- 10TH MAGNITUDE GUIDE STARS

PLANETARY TRACKING

- STABILITY – 0.01 ARC SEC
- 0.10 SEC. TO 45 MIN.

MOT VERSUS OAO POINTING REQUIREMENTS

This chart compares the fine-pointing requirements of the MOT and OAO (the latter is considered to be state of the art). These requirements reflect the degree of difficulty of the attitude control problem in the MOT fine-pointing mode.

The MOT control range is proportionately less than the OAO ranges since an intermediate pointing mode is being considered for MOT.

In the fine-pointing mode the spacecraft pointing stability is highly reliant on the characteristics of the fine-pointing sensor. The performance of this device is very sensitive to the amount of its incident radiation (effective collecting aperture and star magnitude) as well as its required linear range. The latter two collecting apertures are based on using up to 50 percent of the available light, although the MOT light-sharing ratio has not been firmly established. The ultimate limit of the sensor's performance will be strongly influenced by the amount of noise in its output signal. The Goddard noise equivalent signal entry indicates how this noise varies with input light (star magnitude).

MOT VS OAO POINTING REQUIREMENTS

	OAO GODDARD	OAO PRINCETON	MOT
SPACECRAFT CONTROL STABILITY	± 1.1 ARC SEC 7th MAG	±0.1 ARC SEC 7th MAG	± 0.01 ARC SEC 10th MAG
FINE-POINTING CONTROL RANGE TOTAL LINEAR	 ± 2¼ MIN OF ARC ± 28 ARC SEC	 ± 4 MIN OF ARC ± 2 ARC SEC	 ± 15 ARC SEC ± 1 ARC SEC
STAR MAGNITUDE COVERAGE	+1 TO +10	0 TO +7	0 TO +10
EFFECTIVE COLLECTING APERTURE	11 - INCH DIA	< 22-INCH DIA	< 81 - INCH DIA
NOISE EQUIVALENT SIGNAL	0.1 ARC SEC 2ND MAG 1.1 ARC SEC 7th MAG 50 ARC SEC 10th MAG	0.005 ARC SEC 7th MAG	0.001 ARC SEC 10th MAG
APPROXIMATE LAUNCH DATE	1967	1968	1980

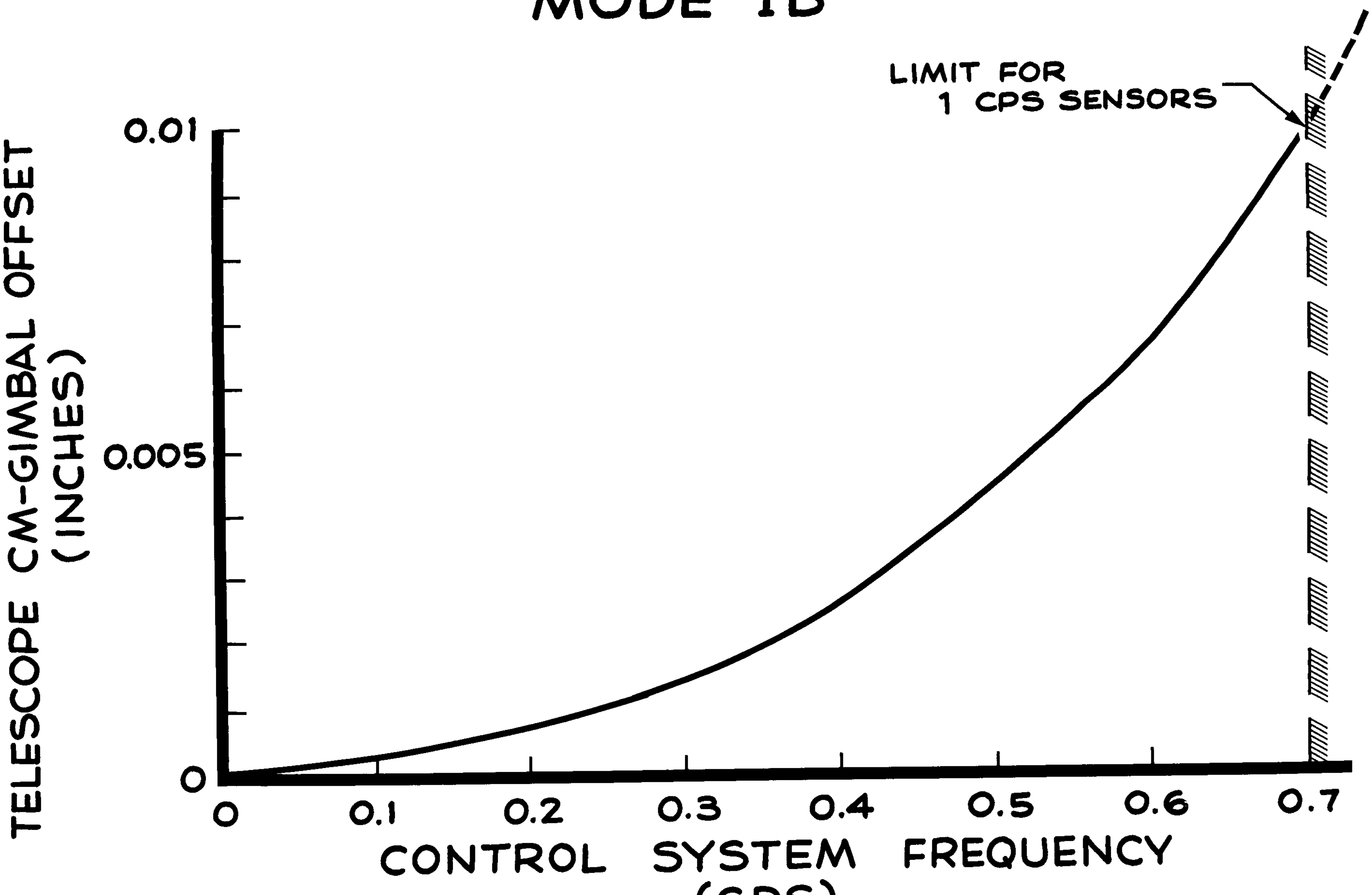
CONTROL FREQUENCY REQUIREMENTS

In Mode I, disturbance torques generated by crew disturbances must cause reaction by the control system to prevent telescope motion. Since these disturbances can be rapid, this results in a requirement for a high response control system. For the rigid vehicle, assuming an astronaut accelerating to 5 feet per second in 0.5 second, this results in an impossible requirement of an 11 cps control system.

In the gimbaled mode, this same disturbance is transmitted to the telescope through offsets between the gimbal axis and the telescope center of mass. The control frequency requirements thus vary with this offset as shown in the figure. Since most fine-pointing sensors exhibit only very low frequency response, it is almost mandatory to keep the control frequencies in the band shown. The resulting low tolerances on the offsets would undoubtedly be extremely difficult to obtain, particularly in light of the expendable usages.

CONTROL FREQUENCY REQUIREMENTS

MODE IB



OPERATIONAL MODE EVALUATION

Studies determined the impact of the various configurations on the probability of demonstrating the feasibility of the MOT GC&SS. These studies were concentrated in the GC&SS fine-pointing mode where the configuration impact is greatest. There is little chance of success in any mode where crew disturbances are capable of reaching the MOT. The tethered mode is also rated low because of the uncertainties associated with the cable dynamics. The other mode ratings are similar with respect to the MOT fine-pointing feasibility, the differences being in the configuration's impact on other control system requirements. For example, the floating socket mode will require a continual orbit-keeping ability on the MORL in order to prevent contact with the free floating MOT. This presents a severe operational disadvantage, but with the control hardware envisaged in 1975 to 1980 or sooner, the risk is small from a feasibility standpoint.

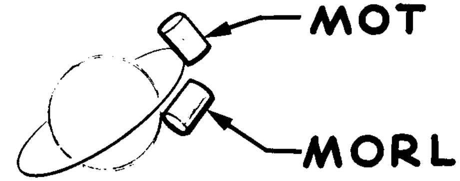
OPERATIONAL MODE EVALUATION

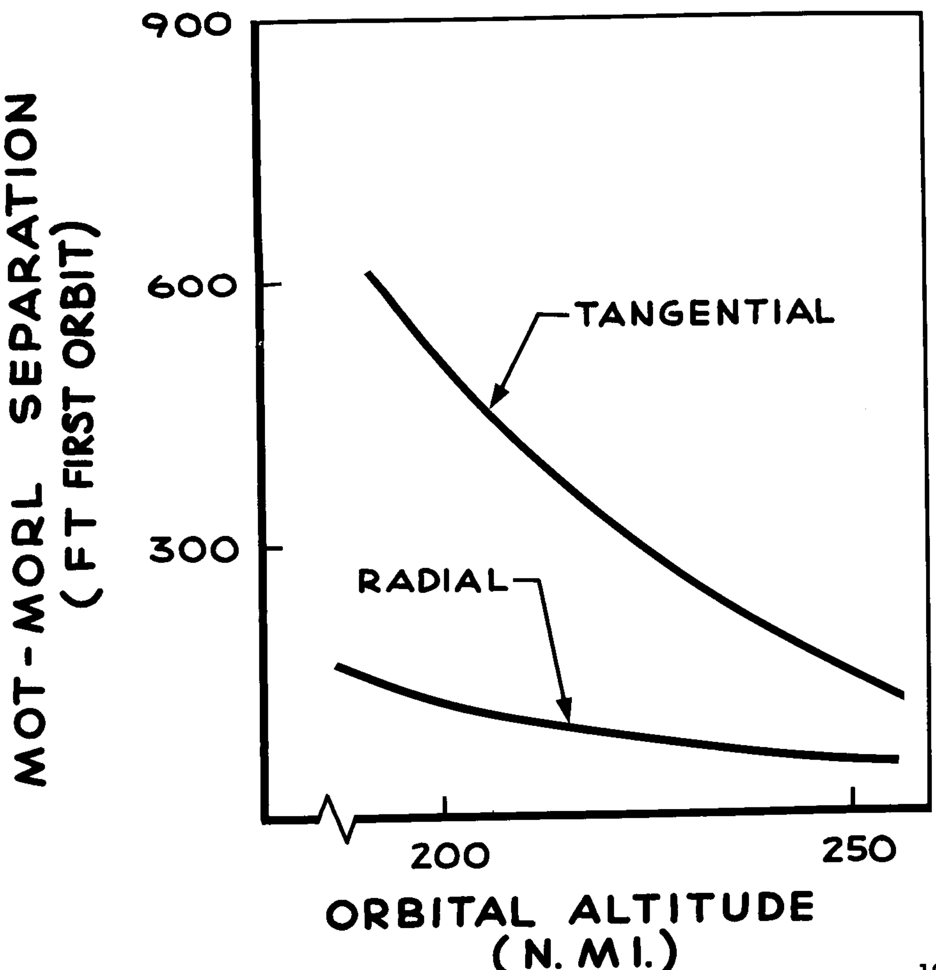
MODE	IMPORTANT CHARACTERISTICS	PROBABILITY OF CONTROL FEASIBILITY
IA RIGID	• MAN'S DISTURBANCES • HIGH CONTROL RESPONSE • COMBINED VEHICLE PENALTY • MORL MANEUVERING	VERY LOW
IB GIMBALED	• PARTIAL DISTURBANCES • MORL MANEUVERING	LOW
IIA TETHERED	• PARTIAL DISTURBANCES	LOW
IIB FLOATING SOCKET	• CONTINUOUS, ACCURATE ORBIT-KEEPING	MEDIUM
IIC INTERMITTENT DOCKING	• REMOTE CONTROLLED DOCKING	HIGH
IIIA IIIB ALWAYS SEPARATE IIIC	• VERY SIMILAR	HIGHEST

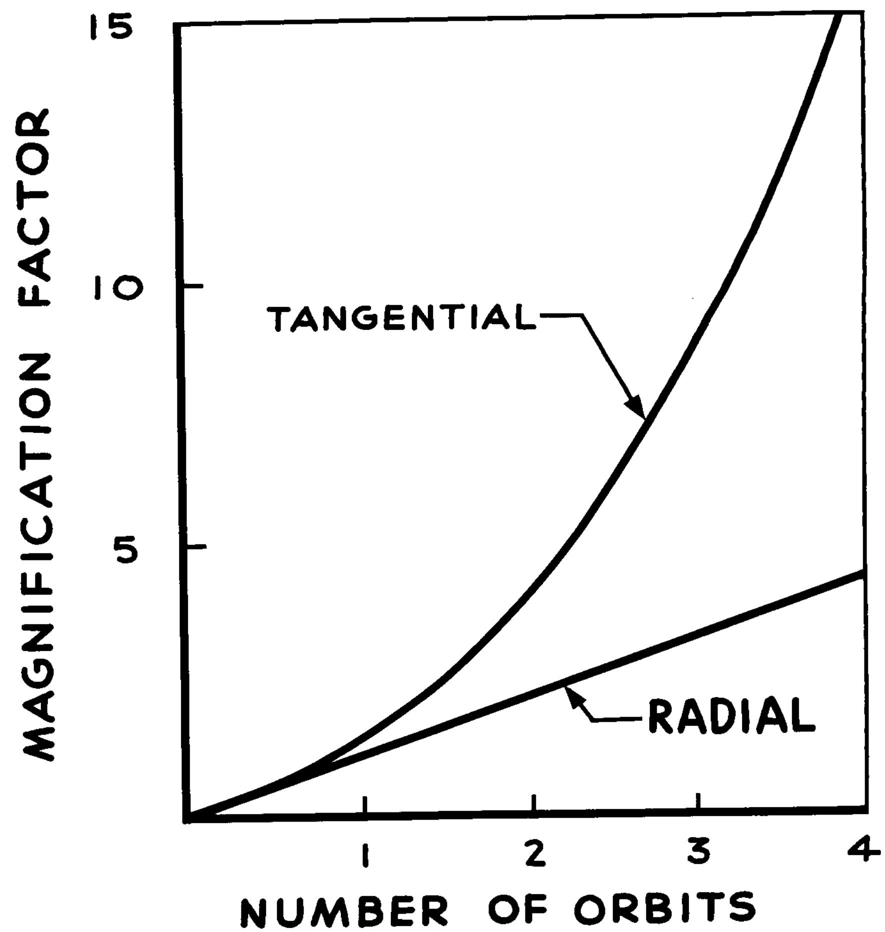
ORBIT-KEEPING REQUIREMENTS

Studies were performed to determine the orbital separation that would occur in the detached modes due to differences in aerodynamic drag between the two vehicles. The analysis indicates, for example, 300 to 600 feet displacement between the two vehicles could occur during the first orbit at 200 nautical miles. Another result of the analysis is that the tangential separation between the two vehicles increases rapidly with successive orbits while the radial separation does not. After the fourth orbit, about sixteen times as much tangential separation has occurred as that after the first orbit. Because of the preliminary nature of the definitions of the two vehicle configurations, the actual separations are only approximate, but they do indicate the importance of the effect. Separations due to differential gravity were investigated and found negligible. The results also indicate that the body with the greater drag lags at first but then loads the second body.

ORBIT-KEEPING REQUIREMENTS





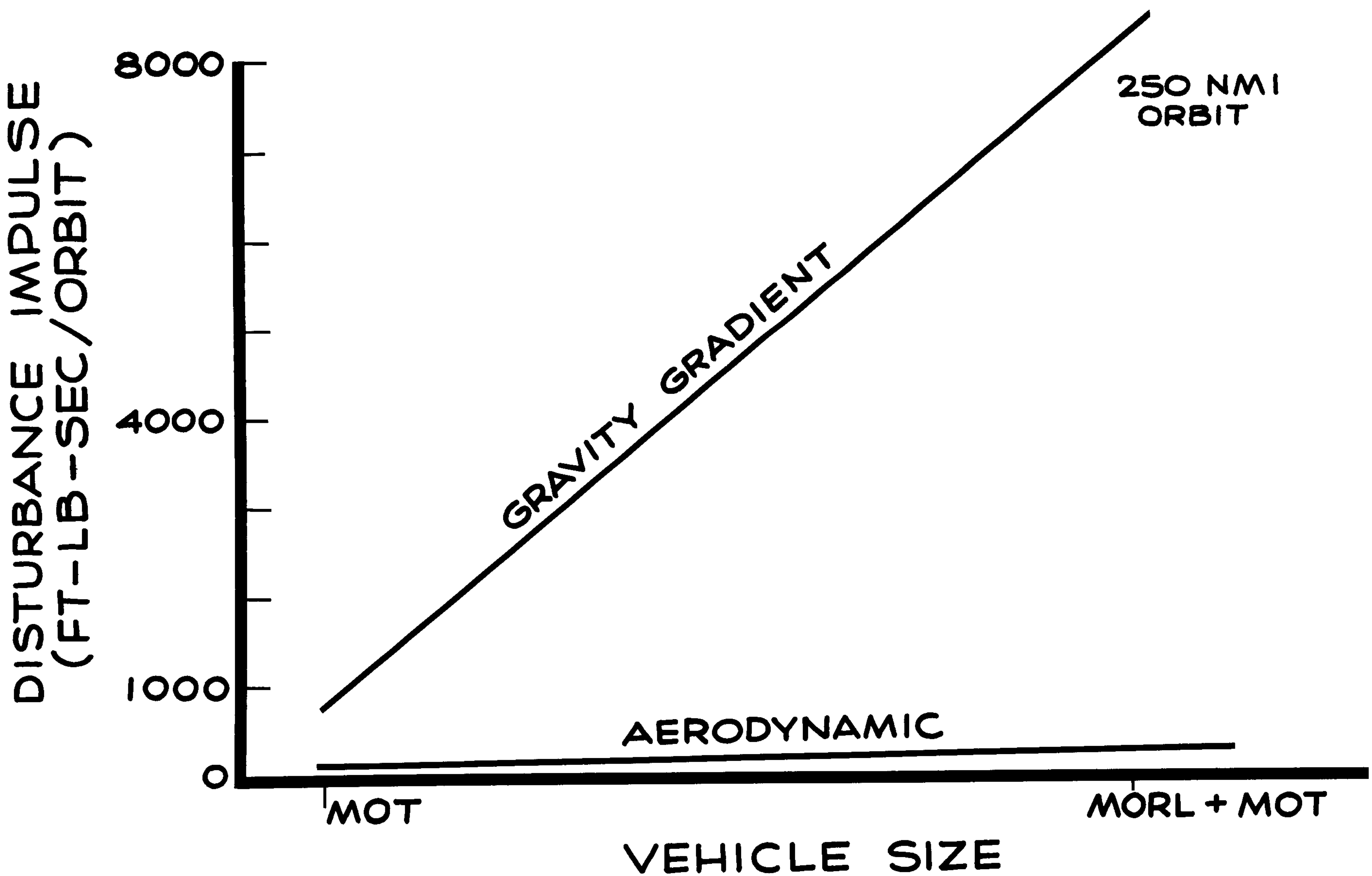


EXTERNAL DISTURBANCES

Studies of the external disturbances expected on the MOT were performed to size the control system hardware. This figure indicates that gravity gradient disturbances are by far the most important effect. The magnitude of the disturbances indicates that a momentum exchange attitude control system is required to counter the disturbances between desaturation periods. The chart indicates also the size advantage for the detached mode. This advantage manifests itself, not only in size, weight, and power savings, but with a smaller momentum exchange system, fewer problems are to be expected in attaining the required pointing accuracies.

Detailed equations have been developed to indicate both the cyclic and cumulative components of the disturbances. The equations are not configuration sensitive and therefore future configuration iterations can be quickly accomplished.

EXTERNAL DISTURBANCES



FLEXIBLE VEHICLE STUDY PROGRAM

Early in the MOT study program, it became evident that structural flexibility could be a major problem area. Accordingly, the study program outlined here is being initiated. Boeing is studying the structural deflections that arise from distributed external disturbances (i.e., gravity gradient and aerodynamic forces) against which, at one point, the control system momentum exchange device reacts. Boeing will also determine the flexible vehicle dynamics.

When these tasks are completed, General Electric will incorporate these characteristics in a control-structural flexibility simulation. This simulation will contain those control system characteristics which may potentially excite the structural modes. Such characteristics as spinning wheel unbalances (i.e., GMG rotor) and the control loop dynamics and noise are expected to be important.

FLEXIBLE VEHICLE STUDY PROGRAM

STRUCTURAL DEFINITION

- DETERMINE STATIC POINTING ERRORS DUE TO FLEXIBILTY
- DETERMINE FLEXIBLE-VEHICLE DYNAMICS

CONTROL-STRUCTURAL STUDY

- DETERMINE CONTROL SYSTEM CHARACTERISTICS THAT MAY EXCITE STRUCTURAL RESONANCES
- SIMULATION OF ABOVE CHARACTERISTICS WITH DETAILED CONTROL SYSTEM

FINE-POINTING SENSOR STUDY PROGRAM

In proving the feasibility of orientating the MOT within the ±0.01 arc second pointing requirement, the characteristics of the fine-guidance sensor become a critical problem. To investigate this, a study program was initiated.

From the definition of the control requirements derived from the observational program, it became evident that the three distinct categories of sensors required were: on axis, off axis, and planetary tracking.

From a preliminary study and state-of-the-art survey, one critical sensor problem will be selected for integration into the detailed control system simulations. All sensor characteristics pertinent to this simulation will be investigated in detail.

STUDY PROGRAM

FINE-POINTING SENSOR

TASK	PROGRESS (%)
• DEFINE OBSERVATIONAL PROGRAM CONTROL REQUIREMENTS	80
• INVESTIGATE FINE POINTING SENSORS TO SATISFY ALL ABOVE REQUIREMENTS	40
• SELECT MOST DIFFICULT SENSOR PROBLEM	0
• DEFINE SELECTED SENSOR CHARACTERISTICS APPROPRIATE TO DETAILED SYSTEM EVALUATION	10

FINE-GUIDANCE SENSOR REQUIREMENTS

Because the fine-guidance sensor represents a crucial problem area, an extensive state-of-the-art survey is being made of their characteristics. The table shown is thought to illustrate the best available blend of the control system requirements on the sensor performance and the extrapolated state of the art in sensors. The requirements and available characteristics will be continually iterated during the course of the study.

To assist in defining the extrapolated state of the art, a comprehensive survey is being conducted. To date, the state-of-the-art survey has considered the following sensors:

1) Four-Quadrant Beam Splitter:
   a) General Electric Fine Optics Error Sensor,
   b) Stratoscope II;
2) OAO Boresight Tracker;
3) General Electric (LEMD) Planet Tracker;
4) Goddard Experiment Package:
   a) Fine-Pointing Sensor;
5) Princeton Experiment Package.

FINE-SENSOR REQUIREMENTS

FIELD OF VIEW	± 15 ARC SEC
LINEAR RANGE	± 1 ARC SEC
NULL UNCERTAINTY	0.001 ARC SEC
LINEARITY	10 % OF SLOPE
TOTAL UNCERTAINTY	GREATER OF 0.002 ARC SEC OR 10 % OF VALUE
NOISE	0.001 ARC SEC RMS 10TH MAGNITUDE FREQUENCIES UNKNOWN
FREQUENCY RESPONSE	1 CPS

OPERATIONAL MODE EVALUATION

EVALUATION METHOD

The general method used to evaluate the operational modes was as outlined below.

Evaluation criteria were derived from the MOT program objectives. These criteria were designed to measure the capability of each mode to meet the system objectives.

The modes were then defined by a consistent set of ground rules.

Each mode was then assessed by each of the criteria. Quantitative values were determined wherever possible. Where this was not possible, qualitative judgments were made; these judgments were used to compare the various modes.

These assessments were then compared in a matrix and modes with exceptionally good and bad features were noted. In addition, a comparison was made within each mode to determine which variation was best.

All modes with exceptionally bad features were eliminated.

The worst modes within each class were also eliminated.

The best of the remaining modes or combinations of modes were retained for further study.

EVALUATION METHOD

- DEFINE EVALUATION CRITERIA
- DEFINE EACH MODE
- ASSESS EACH MODE AGAINST EACH CRITERION
- FIND--
  - EXCEPTIONALLY GOOD FEATURES
  - EXCEPTIONALLY BAD FEATURES
  - COMPARE WITHIN MODES
- ELIMINATE MODES WITH POOREST RATINGS
- ELIMINATE WORST MODES WITHIN EACH CLASS
- CHOOSE BEST OR REMAINING MODES OR COMBINE

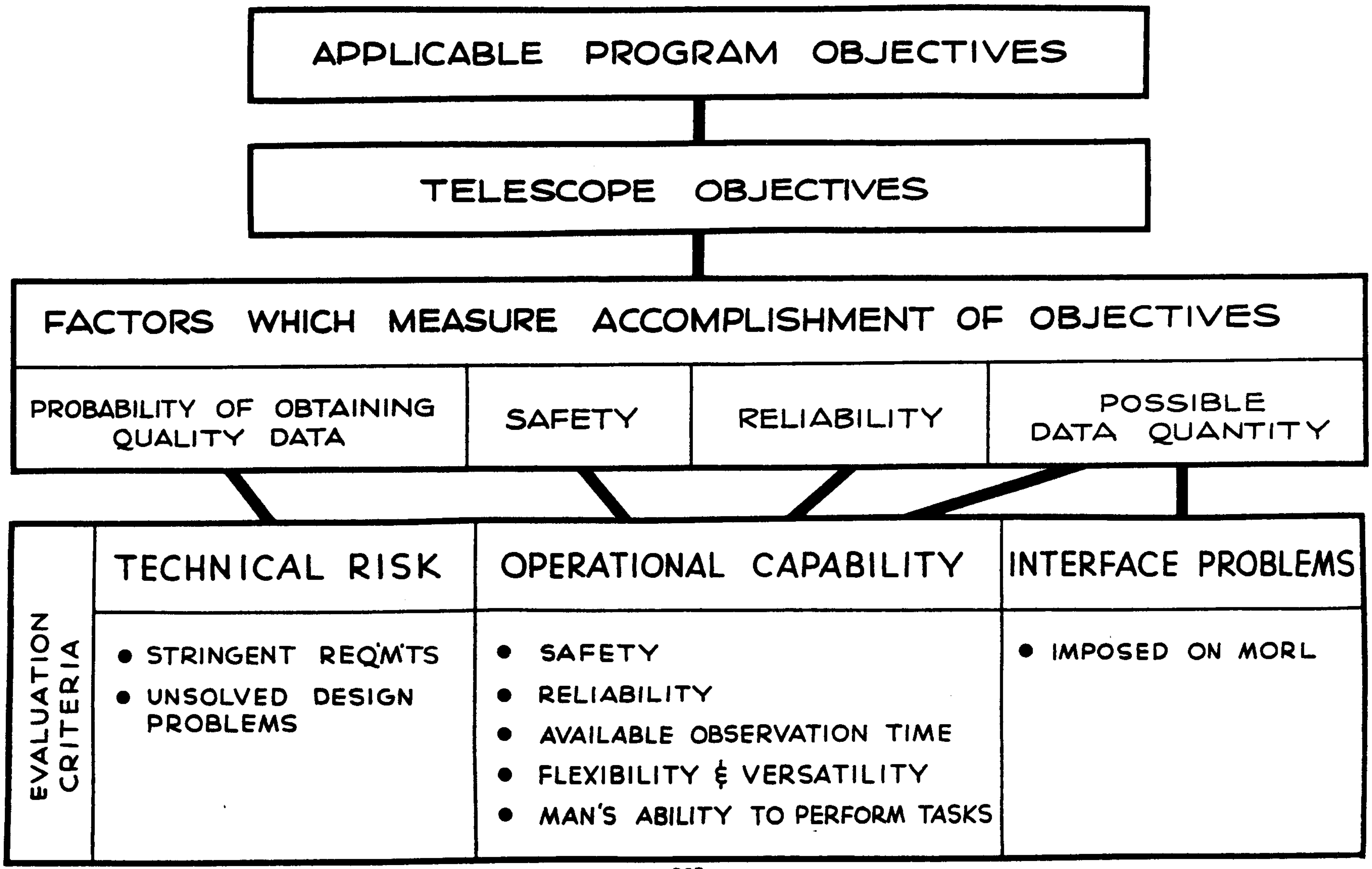
DERIVATION OF EVALUATION CRITERIA

In deriving evaluation criteria it is necessary to logically relate the pertinent NASA program objectives to evaluation criteria. These objectives are to: investigate the possible operational modes with special emphasis on the way man will be used to support the laboratory; and accomplish the necessary engineering studies, analysis, design, and planning required to select the best operational mode and design of the telescope.

In these investigations and in the selection it is necessary to consider the reason that the telescope was placed in orbit. This may be defined as obtaining the maximum amount of data of required quality in the safest and most reliable manner. The degree to which a particular mode meets this objective can then be measured by the following factors: the probability of obtaining data of the required quality; the quantity of data that can be obtained; the safety factor; and reliability.

The illustration shows that the probability of obtaining data of the required quality is measured by technical risk; the quantity of data that can be obtained is measured by operational capability and MORL interface constraints and requirements; and that safety and reliability were used as measures of operational capability. Other measures of operational capability are available observation time, flexibility and versatility, and the difficulty of man's role.

EVALUATION CRITERIA DERIVATION



OVERALL EVALUATION

Summary

Here we summarize the assessment of the modes against the criteria.

In the following pages we will examine the methods used to obtain the numbers shown and compare the modes, criterion by criterion.

SUMMARY

		SYSTEM CONCEPTS							
		MODE I - RIGID MOUNT		MODE II - INTERMITTENT DOCKING			MODE III - SEPARATE		
		IA RIGID	IB GIMBALED	IIA TETHERED	IIB FLOAT-SOCKET	IIC REMOTE	IIIA NO CABIN	IIIB CABIN	IIIC SHUTTLE
TECHNICAL RISK		VERY POOR	POOR	POOR	FAIR	FAIR	MODERATELY GOOD	MODERATELY GOOD	FAIR
OPERATIONAL CAPABILITY	AVAILABLE OBSERVATION TIME	82.5%	80 %	80%	80%	78.5%	73.5%	80.5%	79 %
	RELIABILITY	.96	.96	.94	.95	.95	.97	.97	.96
	SAFETY	.9999	.9999	.99	.99	.9818	.9576	.9602	.99
	FLEXIBILITY AND VERSATILITY	VERY POOR	VERY POOR	POOR	VERY POOR	GOOD	FAIR	FAIR	GOOD
	MAN'S ABILITY TO PERFORM ASSIGNED TASKS	VERY GOOD	VERY GOOD	GOOD	GOOD	GOOD	VERY POOR	POOR	FAIRLY GOOD
MORL INTERFACE CONSTRAINTS AND REQUIREMENTS		VERY SEVERE	VERY SEVERE	SEVERE	VERY SEVERE	MODERATE	VERY FEW	FEW	FEW

TECHNICAL RISK

Technical risk is defined as the probability of systems not meeting design or operational requirements in the specified environment by the specified date. In comparing one mode of operation with another, it is necessary to identify those systems having technical risks that are mode sensitive. The ratings in the summary table were arrived at by determining the number and severity of stringent requirements and unsolved problems in each mode.

The following paragraphs summarize the reasons for the ratings on the summary table.

Mode IA was rated "Very Poor" due to the severe design requirement in which the control system must cope with disturbances imparted to the vehicle by man, and because of the dependence of the mode on the MORL design.

Mode IB was rated a better risk than IA because the gimbal would make it easier to meet the stability requirement. The mode is still a "Poor" risk, however, due to uncertainties in attaining a satisfactory gimbal design.

Mode IIA was rated "Poor" due to uncertainties of the cable dynamics and their effects on the MOT fine-stability control requirements, and the effects of repeated dockings on the optical system.

Modes IIB, IIC, and IIIC were all rated "Fair," and Modes IIIA and IIIB were rated "Moderagely Good." The principal technical risks of each of these modes is shown on the chart; however, in Modes IA, IB, and IIA, these risks were not considered severe.

TECHNICAL RISK

MODE	RATING	RISK
I A	VERY POOR	ATTITUDE STABILITY CONTROL
I B	POOR	GIMBAL DESIGN
II A	POOR	CABLE DYNAMICS EFFECT ON STABILITY
II B	FAIR	MORL STATION KEEPING
II C	FAIR	DOCKING EFFECTS ON MOT
III A & III B	MODERATELY GOOD	MAINTENANCE IN SPACE SUIT
III C	FAIR	DOCKING EFFECTS OF SHUTTLE ON MOT

USE OF OBSERVATION TIME

Efficient use of available observation time is a fundamental requirement in order to obtain the maximum amount of data from the MOT. Available observation time has been defined as the night time of each orbit, providing a maximum of 12 hours per day for actual observations. Because the purpose of the MOT is to obtain as much as possible of the required quality of data, the efficient use of observation time becomes important for mode comparisons and evaluation. All orbital night time cannot be used for observation because of requirements for equipment changes, maintenance, routine inspections, and servicing. Observation time will also be lost by slewing and fine stabilization. Other factors affecting observation time use are: travel between the MORL and MOT; docking and undocking requirements; and pressurization and depressurization of the MOT.

To evaluate the effects of these factors on the various modes, a timeline analysis was made for each of the eight modes. A sample 9-day astronomical observation program was established for all seven types of observations: photoelectric photometry, low-dispersion spectra, high-dispersion spectra, stellar photography, high-dispersion infrared spectra, thermoelectric measurements, and planetary photography.

All of the modes except Mode IIIA were fairly close in observation time use at approximately 80 percent. Mode IIIA, where all functions are performed in the spacesuit is low at 73.5 percent, and this is felt to be optimistic because of uncertainties in the portable life support system (PLSS) expendables and overall work-load and stress imposed on the astronaut.

AVAILABLE OBSERVATION TIME

- DETERMINED BY TIMELINE ANALYSIS
- ANALYSIS ACCOUNTS FOR –
  - MAINTENANCE
  - SLEWING & RESTABILIZATION
  - TRAVEL BETWEEN MORL & MOT
  - DOCKING & UNDOCKING
  - PRESSURIZATION & DEPRESSURIZATION
- ALL MODES ABOUT 80% UTILIZATION EXCEPT MODE IIIA – 73.5% – DUE TO PERFORMING OPERATIONS IN A SPACE SUIT

RELIABILITY

The summary table shows that the reliability of all modes is estimated to be nearly the same. The actual reliability numbers are considered preliminary and more confidence can be placed in the differences than in their absolute values. As the differences are not great, reliability has not strongly influenced mode choice. The reliability estimates were derived by evaluating the MOT subsystems in terms of weighting factors. These factors were based on MORL reliabilities as shown in Douglas Report SM-44615, "Report on a System Comparison and Selection Study of MORL," based on 1 year of MORL operation. The MORL weighting factors were determined by counting 1.0 for each 0.001 unreliability found; e.g., the reliability of the MORL structure was estimated as 0.993 and the weighting factor was taken as seven. The MOT weighting factors were estimated by comparing the MOT subsystem requirements with those of the corresponding MORL subsystem and then making an engineering judgment of comparative reliability of each. Although the reliabilities were nearly equal when so estimated, the method did highlight areas of potentially poor reliability.

In Modes IA and IB, the attitude control and stability system must correct man's disturbances, therefore must be somewhat more complicated than for the other modes and must operate more often. In Mode IIA the stability system must operate often to eliminate tether dynamics; the propulsion system must operate often while the MOT is taking data because station keeping is required and the structure is complicated by the tether and docking requirements. In Mode IIB the stability and propulsion systems must operate often to keep the MOT within the floating coupling. In Mode IIIC the propulsion system operates often and the structure system is complicated by docking requirements. In Modes IIA and IIIB the environment control system must be contained in the backpack. And finally, in Mode IIIC the propulsion system must operate often for docking.

RELIABILITY

ESTIMATED FROM PUBLISHED MORL RELIABILITIES

- COMPARED MOT SUBSYSTEM COMPLEXITY
- COMPARED MOT SUBSYSTEM OPERATING TIME

RELIABILITY ABOUT EQUAL FOR ALL MODES

- IIIA & IIIB BEST; IIA POOREST

POOR RELIABILITY AREAS

MODE	SUBSYSTEM			
	STABILITY	PROPULSION	STRUCTURE	ECS
IA & IB	X			
IIA	X	X	X	
IIB	X	X		
IIC		X	X	
IIIA & IIIB				X
IIIC		X		

SAFETY

In this study safety was measured by the probability of no fatal accidents during 6 months of operation, which is considered to be a crew member's duty cycle. Safety was estimated from an analysis of the basic differences between concepts. The absolute values are tentative and emphasis should be placed on the differences between the numbers. Remember also that the goal for the probability of no fatal accidents in 6 months should be extremely high, 0.999 or higher.

As shown in the summary table, the safety of Modes IIC, IIIA, and IIIB is lower than that of the other modes. The low safety value for Modes IIIA and IIIB is primarily due to the possibility of spacesuit pressure loss, the exposure of the astronauts to the space environment (radiation and meteoroids) during the many trips that must be made (one round trip per day), reliability of the astronaut maneuvering units, and the time required to perform tasks in a spacesuit. The low safety value for Mode IIC results from the many times the MOT must dock with the MORL (also one per day). Mode IIA must dock as often but a tethered docking was considered safer. Note that a fatal accident in Modes IIIA or IIIB would result in only one or two deaths, whereas a serious collision involving a Mode IIC docking could result in death for the entire crew.

The low safety ratings of Modes IIIA and IIIB were strong points against these modes. It may be possible to increase the safety of Mode IIC by reducing the number of dockings. The significance of this will appear in the summary discussion.

SAFETY

- STUDY BASED ON 6-MONTH DUTY CYCLE
- SAFETY GOAL 0.999
- SAFETY OF MODES IIC, IIIA, AND IIIB IS LOW
  - IIC DUE TO REPEATED DOCKINGS
  - IIIA AND IIIB DUE TO EXTENDED OPERATIONS IN A SPACE SUIT
- IIC MAY BE IMPROVED BY REDUCING DOCKINGS

FLEXIBILITY AND VERSATILITY

This criterion measures the ability of the MOT concepts to accommodate various operational and design requirements. The desired flexibility of the MOT design for different types of astronomical experiments is primarily a problem of basic telescope configuration choice. This evaluation is therefore an assessment of whether a mode of operation places operational constraints or design-growth constraints on the basic telescope or on MORL. The evaluation shows the degree to which both the MORL and the MOT are penalized by conflicting requirements or constraints.

This approach gives the best ratings in the summary table to modes in which the astronomical observations are performed when the MOT is completely detached and some distance away from the MORL. The modes that fall in this category are IIC, IIIA, IIIB, and IIIC. Modes IIC and IIIC are both rated "Good" but have varying factors. Mode IIC imposes the most design and subsystem requirements and operational constraints on the MORL and the MOT, but compared to IIIC it is also the most versatile in accommodating experiment changes and MOT maintenance. Modes IIIA and IIIB are rated as only "Fair" due to the limitations of spacesuit operations. Mode IIA is rated "Poor" because of the requirements and constraints imposed by the cable on both the MORL and the MOT. Modes IA, IB, and IIB are rated "Very Poor" because the MORL is virtually a slave to the MOT during telescope operations. In addition, those concepts have design and subsystem interfaces which would limit design changes or the growth potentials of both the MORL and the MOT.

FLEXIBILITY & VERSATILITY

- MEASURES MOT ABILITY TO ACCOMODATE VARYING OPERATIONAL & DESIGN REQUIREMENTS

- SEPARATE MODES ARE BEST
  - MORL NOT SLAVED TO MOT
  - NO SUBSYSTEM DEPENDANCE

MAN'S ABILITY TO PERFORM TASKS

The ability of man to perform his required tasks was evaluated by determining the number and severity of problem areas in each mode. This table shows the serious problem areas applicable to each mode and the difficulty of solving each problem. Modes IIIA and IIIB have both the most serious and the highest number of problems. On the summary chart they are rated "Very Poor" and "Poor," respectively. The cause of these problems is almost entirely the requirements to service and repair the MOT in a spacesuit; in Mode IIIB the problem is not as severe as in Mode IIIA because the suit need not be pressurized while working in the cabin. Modes IIA, IIB, IIC, and IIIC all have problems with respect to man's ability to assist in docking the MOT and MORL or shuttle. These problems, however, were considered to be considerably less severe than those encountered in Modes IIIA and IIIB; in addition, the docking problems with the shuttle (Mode IIIC) were considered to be slightly more severe than those involved in docking the MOT and MORL (Modes IIA, IIB, and IIC). To show these differences, Modes IIA, IIB, and IIC were given "Good" ratings and Mode IIIC a "Fairly Good" rating. Modes IA and IB were judged to have no difficult problems with regard to man's task and were rated "Very Good" in the summary.

MAN'S ABILITY TO PERFORM TASKS

DETERMINED BY NUMBER & SEVERITY OF PROBLEMS

MODE	PROBLEMS			
	ACCESS TO MOT	TRANSPORT EQUIPMENT ETC.	PERFORM FUNCTIONS IN MOT CABIN	MANEUVERING & DOCKING
IA & IB				
IIA & IIB				MODERATELY DIFFICULT
IIC				DIFFICULT
IIIA	VERY DIFFICULT	VERY DIFFICULT	VERY DIFFICULT	
IIIB	VERY DIFFICULT	VERY DIFFICULT		
IIIC				DIFFICULT

MORL INTERFACES AND CONSTRAINTS

The MOT and the MORL design and operational interfaces define the basic differences in requirements and constraints imposed on the MORL for the eight modes of operation that are being evaluated. The interfaces for each mode of operation were identified in terms of the requirements of design, function, subsystems, and man's role. Mode-insensitive requirements on MORL are not listed.

Certain interface problems and constraints were most influential in determining the ratings shown in the summary.

In Modes IA and IB the MOT constrains the MORL crew and machine movements during telescope observations. In addition, MORL structural and subsystem changes are required. In Mode IIB the MORL is required to keep station within a very limited space. In addition, changes to the MORL structure and subsystems are required since MOT is dependent on MORL subsystems when docked. In Mode IIA the MORL is required to keep station within the tether length (not as severe as in Mode IIB), and the MORL structure and subsystems must be revised since MOT is dependent on MORL when docked. And, in Modes IIC, IIIA, IIIB, and IIIC the interface problems and constraints were not severe when compared to those just listed.

On the basis of these results, Modes IA, IB, and IIB were judged to have "Very Severe" interface problems and constraints; in Mode IIA the problems and constraints were judged to be "Severe"; for all other modes the problems and constraints were all judged "Moderate" or "Few."

MORL INTERFACES & CONSTRAINTS

DETERMINED BY NUMBER & SEVERITY OF PROBLEMS

MODE	MOST SEVERE PROBLEMS & CONSTRAINTS		
	RESTRICT MORL CREW MOVEMENTS	MORL STRUCTURE & SUBSYSTEM CHANGES	MORL STATION-KEEPING
IA & IB	X	X	
IIA & IIB		X	X

SUMMARY TABLE

The crosshatched blocks shown on the summary table indicate unsatisfactory assessments.

The table shows that Modes IA, IB, IIA, and IIIA each have three low ratings. With the first three modes they are technical risk (stability), flexibility, and interface constraints and requirements. In Mode IIIA they are utilization of available observation time, safety, and man's ability to perform tasks. Modes IIB and IIIB are each rated low under two criteria. In Mode IIB they are flexibility and interface constraints and requirements; in Mode IIIB they are safety and man's ability to perform tasks. Mode IIC is rated low against only one criterion—safety, while Mode IIIC has no low ratings.

Of the above ratings, those with the double crosshatch (Mode IA, stability; Modes IIIA and IIIB, safety) are considered to be below acceptable standards.

The conclusions drawn from these data are shown on the following page.

SUMMARY

		SYSTEM CONCEPTS							
		MODE I – RIGID MOUNT		MODE II – INTERMITTENT DOCKING			MODE III – SEPARATE		
		I A RIGID	I B GIMBALLED	II A TETHERED	II B FLOAT-SOCKET	II C REMOTE	III A NO-CABIN	III B CABIN	III C SHUTTLE
	TECHNICAL RISK	VERY POOR	POOR	POOR	FAIR	FAIR	MODERATELY GOOD	MODERATELY GOOD	FAIR
OPERATIONAL CAPABILITY	AVAILABLE OBSERVATION TIME	82.5%	80%	80%	80%	78.5%	73.5%	80.5%	79%
OPERATIONAL CAPABILITY	RELIABILITY	.96	.96	.94	.95	.95	.97	.97	.96
OPERATIONAL CAPABILITY	SAFETY	.9999	.9999	.99	.99	.9818	.9576	.9602	.99
OPERATIONAL CAPABILITY	FLEXIBILITY AND VERSATILITY	VERY POOR	VERY POOR	POOR	VERY POOR	GOOD	FAIR	FAIR	GOOD
OPERATIONAL CAPABILITY	MAN'S ABILITY TO PERFORM ASSIGNED TASKS	VERY GOOD	VERY GOOD	GOOD	GOOD	GOOD	VERY POOR	POOR	FAIRLY GOOD
	MORL INTERFACE CONSTRAINTS & REQUIREMENTS	VERY SEVERE	VERY SEVERE	SEVERE	VERY SEVERE	MODERATE	VERY FEW	FEW	FEW

SUMMARY AND CONCLUSIONS

Modes IA, IIIA, and IIIB were eliminated by their unacceptably low ratings as discussed previously. This left only Mode IB of the rigid mount and IIIC of the separate modes. A comparison of Mode II variations was then made. Mode IIA was rated low against three criteria, Mode IIB against two criteria, and Mode IIC against one. On this basis Mode IIA was eliminated. The evaluations therefore chose Modes IB, IIB, IIC, and IIIC as the most promising of the eight proposed operational modes. These four modes were then further examined.

Modes IB and IIB are modes closely associated with the MORL and, according to the summary table, have similar ratings against all criteria except technical risk, where IB is poor. This poor rating is mainly due to the difficulty of demonstrating that sufficient attitude stability can be achieved with any gimbal concept. The stability problem will certainly be minimized in the physically uncoupled modes such as IIB, IIC, and IIIC; but it will probably be a major task to demonstrate, even in these cases, that the 0.01-arc-second stability can be achieved. It is recommended, therefore, that IIB be retained as the most likely candidate for a closely associated mode and that consideration of the gimbaled mode be deferred until the degree of stabilization difficulty can be ascertained for modes in which the telescope is physically uncoupled.

Of the two remaining modes that involve remote operation (IIC and IIIC), both have similar ratings, with IIC scoring slightly lower in safety and reliability but with a better rating in man's ability to perform tasks. This better rating of IIC is given because major maintenance or repair will be easier. The best compromise appears to be to select Mode IIIC and add to it the capability of docking; thus, creating a hybrid mode between IIC and IIIC.

CONCLUSIONS

- ELIMINATE MODES IA, IIIA, AND IIIB DUE TO LOW RATING
- ELIMINATE IIA – MORE TECHNICAL RISK THAN IIB & IIC
- OF REMAINING MODES
    - IIB BEST OF CLOSELY ASSOCIATED MODES
    - IIC AND IIIC COMBINED
- RECOMMEND
    - STUDY MODE IIC/IIIC HYBRID & IIB
    - DEFER IB INVESTIGATION

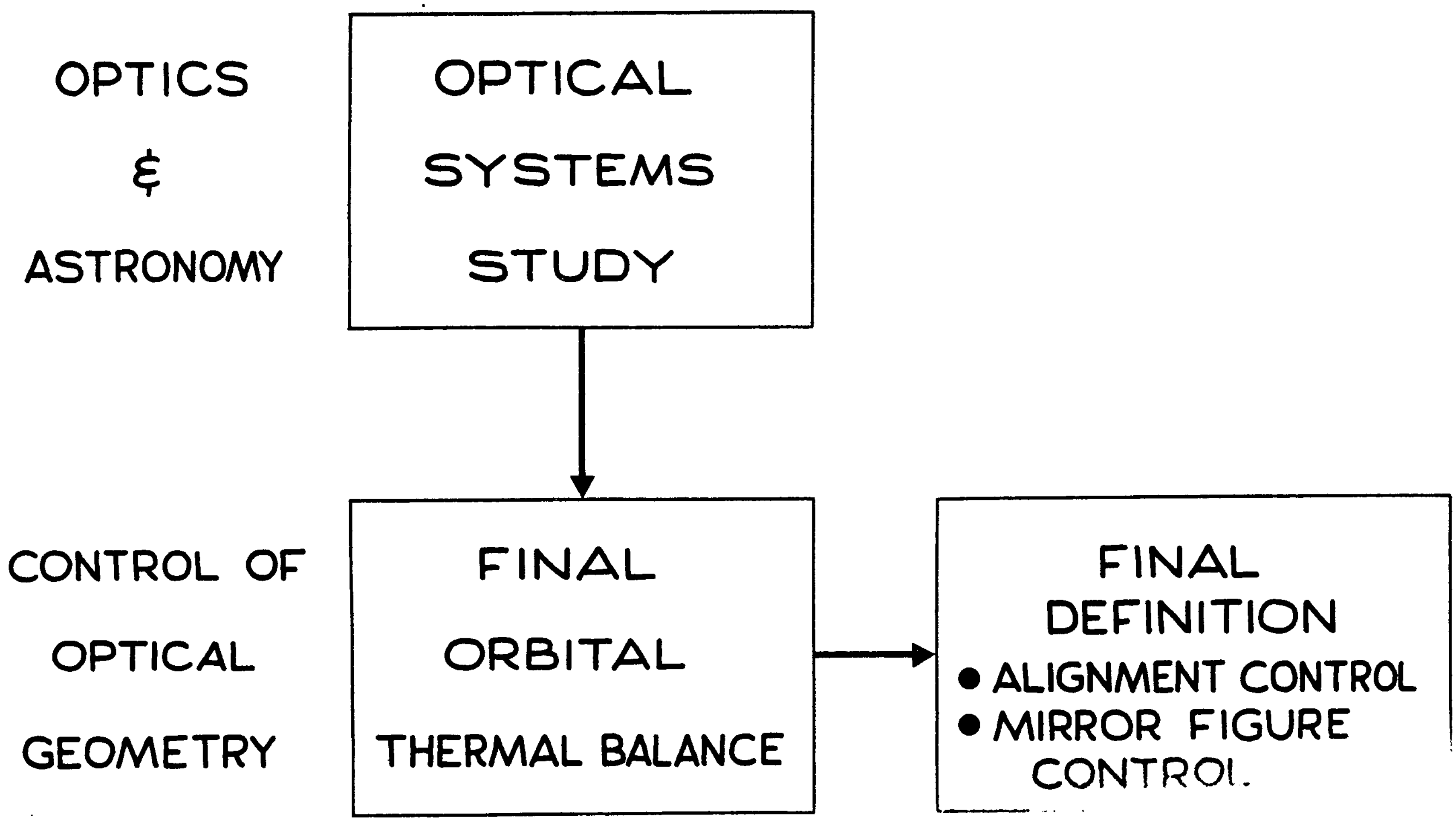
MIDTERM THROUGH FINAL

Items Insensitive to Mode

The principal events during the final half of the study are shown in the accompanying chart. Inputs in the area of astronomical observations resulting from the midterm briefing will be reviewed and a redefinition of these observations formulated, if necessary. An optical systems study will be made to select the final Cassegrainian system to be used. Some slight modifications are anticipated in the area of optical tolerances as a result of the final selection. These new tolerances will feed into the thermal balance analysis. From this work a final definition will be made of the required alignment system. Final definition of the system to control the mirror figure is a goal which may be reached during the course of the study. This particular problem, however, may well require follow-on work.

MIDTERM THROUGH FINAL

ITEMS INSENSITIVE TO MODE



MIDTERM THROUGH FINAL

Items Sensitive to Mode

The mode evaluation discussed in this report has provisionally selected two modes of operation for further study; a hybrid of Modes IIC and IIIC and Mode IIB. The future effort shown in the accompanying chart will be principally directed at making a final recommendation to NASA as to the mode of operation for follow-on study. The method used to make this selection will be similar to that employed in the first half of the study. Particular emphasis, however, will be given to the operational and logistics problems associated with each mode and to attitude control and stabilization.

A final definition will also be made of areas where state-of-the-art advances will be necessary.

MIDTERM THROUGH FINAL

ITEMS SENSITIVE TO MODE